THE VIKING FORMATION

CENTRAL ALBERTA

G.F. STANSBERRY

1957

UNIVERSITY OF ALBERTA

FACULTY OF ARTS & SCIENCE

DEPARTMENT OF GEOLOGY

The undersigned hereby certify that they have read and recommend to the School of Graduate Studies for acceptance, a thesis entitled "The Viking Formation, Central Alberta", submitted by Gerald Francis Stansberry, B. Sc., in partial fulfilment of the requirements for the degree of Master of Science.

Professor

Professor

Professor

April, 1957.

UNIVERSITY OF ALBERTA

THE VIKING FORMATION, CENTRAL ALBERTA

A DISSERTATION

Submitted to the School of Graduate Studies in partial fulfilment of the requirements for the degree of Master of Science.

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by

GERALD FRANCIS STANSBERRY

EDMONTON, ALBERTA

APRIL, 1957.

ABSTRACT

A study of the Viking sandstone was made for the following four wells in Central Alberta: Imperial Norbuck 2-6, Imperial Joffre 2-21V, Imperial Armena 6-11V, and Superior Joseph Lake 11. Seven Foraminifera, one gastropod, four sporomorphs, thirty three thin section, and six suites of heavy minerals are described. The Viking, which shows no evidence of diachronism, was probably derived from pre-existing sediments to the west, and deposition may have taken place slowly in a shallow, marine, partially landlocked sea under slightly reducing conditions. Radioactive dating on glauconite and a bentonitic ash yielded dated of 63 and 45 million years respectively. These ages are thought to be low because of potassium adsorption and argon leakage.

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CHAPTER ONE

INTRODUCTION

This work was initiated to determine whether the Lower Cretaceous Viking formation in the Joarcam, Joffre, and Keystone areas of Central Alberta has an identity of age, source, and environment of deposition.

PREVIOUS WORK

The name Viking was first introduced into geological literature by S. E. Slipper (1918) while working for the Geological Survey of Canada. Slipper again used the name Viking in 1919 (S.E. Slipper, 1935) in a report on oil and gas in Alberta, Saskatchewan, and Manitoba.

Hume (1933) gave evidence for correlation of the Viking sand in the Viking field with the Pelican sand of the Athabasca River area.

Hume and Hage (1941) in a report on East-Central Alberta outlined the prospects for oil and gas in the Viking sand.

Nauss (1945) showed a probable correlation of the Viking to the Blackleaf sandy member of Southern Alberta. Nauss also noted the absence of the Viking sand in the Vermilion and Lloydminster areas. Nauss (1947) described index microfossils from the Lloydminster shale, some of which are used in Viking correlations.

Layer, et al, (1949) described the Viking sand of the Leduc area in a report essentially dealing with the Devonian section of that field.

Wickenden (1949), in a paper on Cretaceous sections along the Athabasca River, described sections of the Pelican formation and gives unillustrated descriptions of pertinent microfossils.

Bullock (1950) carried out a microfaunal study of the lower part of the Lloydminster shale in the Imperial Eldorena #1 well (Lsd. 4,

Sec. 27, Twp. 57, Rge. 20 W4M) and he obtained a representative suite from below, within, and above the Viking formation.

Bahan (1951), correlated the Pelican and Viking sandstone using microfaunal evidence.

Kroon (1951) outlined the general sedimentary features of the Bow Island sand (using the term Bow Island to embrace the Viking) in Central and Southern Alberta.

Badgley (1952) reported on the Lower Cretaceous of Central Alberta and equated the Pelican formation to the Viking sand. He gave the subsurface stratigraphy based mainly on electrologs and well samples, and dealt with the oil and gas possibilities in Central Alberta.

Hunt (1954) in a report on the Joarcam field in Alberta gave a fairly detailed description of the stratigraphy, structure, and depositional environment of the Viking formation.

Jardine (1954) described generally the lithology, reservoir characteristics, and production data of the Viking in the Joarcam field.

Gammell (1955) described the Viking in Central Alberta giving stratigraphy, origin and accumulation of hydrocarbons, and geologic history.

Magdich (1955) wrote a thesis on the Viking formation of Saskatchewan giving lithology, depositional environment, source, and structure.

MATERIAL USED

The material used in obtaining the information presented in this thesis was obtained from two sources:

(1) Diamond cores from three wells through the courtesy of Imperial Oil at Edmonton. These three wells are listed

below:

Imperial Armena 6-11V in Lsd. 6, Sec. 11, Twp. 48, Rge. 21 W4M, was cored from 3280 feet to 3350 feet with a total core recovery of 62 feet 11 inches (90% recovery).

Imperial Joffre 2-21V in Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M, was cored from 4720 feet to 4788 feet with a total core recovery of 69 feet (101% recovery).

Imperial Norbuck 2-6 in Lsd. 2, Sec. 6, Twp. 47, Rge. 4 W5M, was cored from 5566 feet to 5698 feet (with the exception of 5646 feet to 5649 feet which was not cored) with a total core recovery of 130 feet (101% recovery).

(2) A wireline core from Superior Joseph Lake #11 in Lsd. 12, Sec. 13, Twp. 50, Rge. 22 W4M, had been on file at the University of Alberta. Cores 1 to 21 are from 3229 feet to 3269 feet with a total core recovery of 36 feet 7 inches (91% recovery). Cores 22 to 25 are from 3274 feet to 3285 feet with a total core recovery of 10 feet 11 inches (99% recovery).

ACKNOWLEDGMENTS

The writer wishes to acknowledge the help of Imperial Oil in Edmonton and particularly Mr. R. Sluzar of that company who provided him with four cores for use in this thesis.

Dr. P.J.S. Byrne of the Research Council of Alberta has assisted in x-ray analysis.

Mr. Cole prepared some of the cores for thin sections and thanks are extended to the Petroleum Engineering department for use of their equipment in cutting the cores.

Mr. McCaffrey drafted some of the figures.

Concentrates of glauconite were forwarded to M.I.T. and Minnesota for radioactive age determinations.

The Department of Geology has helped with the cost of plates and this section preparation. The writer also wishes to express his sincerest appreciation to all members of the Department of Geology, for their cooperation and encouragement, especially to Dr. R. E. Folinsbee for his help and criticism in preparing the chapter on geochronology, to Dr. J. Lerbekmo for his help and criticism in preparing the chapter on petrography, and finally to Dr. C. R. Stelck for his help and criticism on the palaeontological part of the thesis.

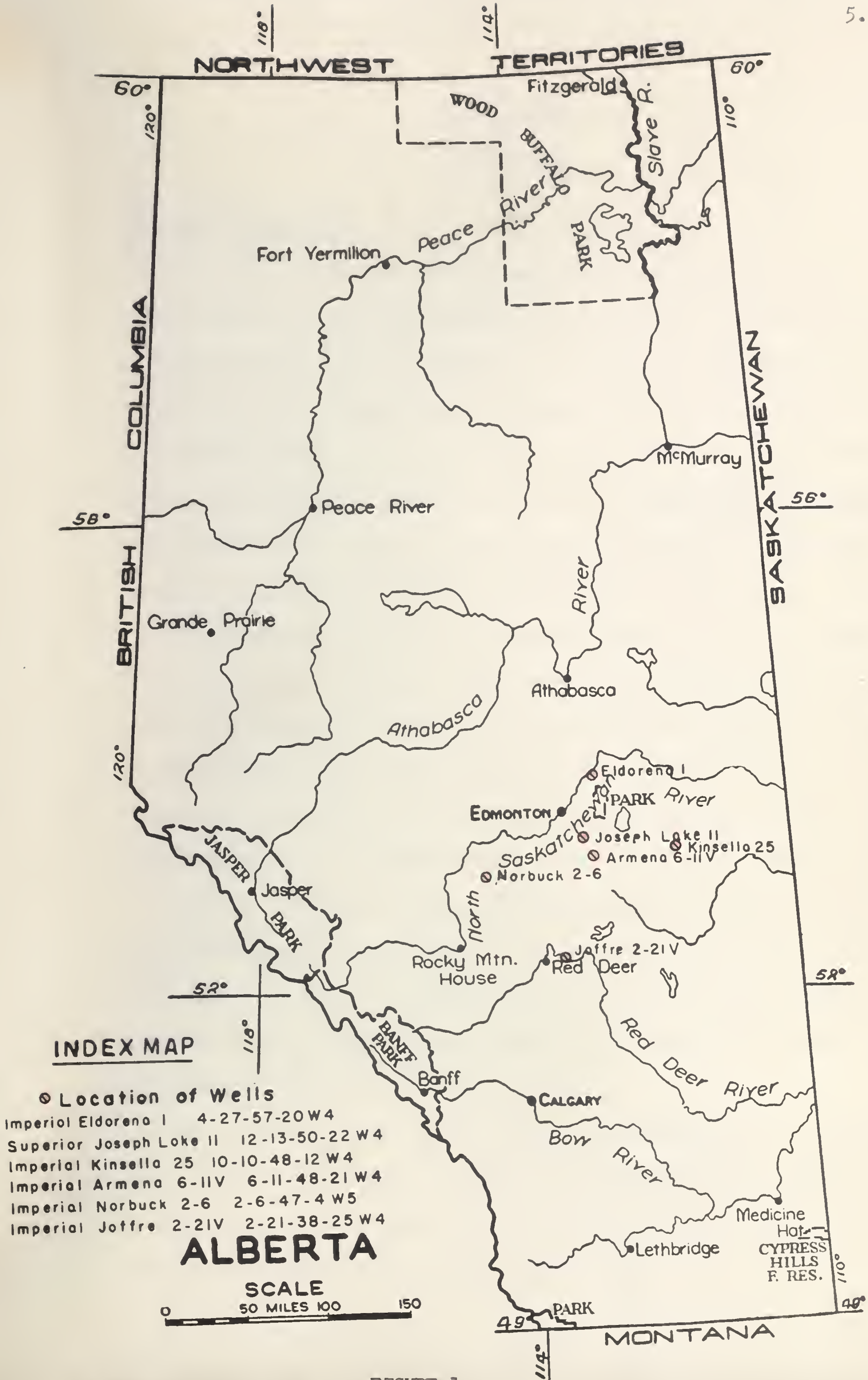
NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
MONTANA
118°
114°
60°
120°
110°
58°
56°
52°
49°
WOOD BUFFALO PARK
Fitzgerald
Slave R.
Peace River
Fort Vermilion
McMurray
Peace River
River
Grande Prairie
Athabasca
Athabasca
Eldorena I
PARK
River
EDMONTON
Saskatchewan
Joseph Lake II
Kinsella 25
Armena 6-IIV
Norbuck 2-6
North
JASPER PARK
Jasper
Rocky Mtn. House
Joffre 2-21V
Red Deer
Red Deer River
BANFF PARK
Banff
CALGARY
Bow River
Medicine Hat
Lethbridge
CYPRESS HILLS F. RES.
PARK
INDEX MAP
Location of Wells
Imperial Eldorena I 4-27-57-20 W4
Superior Joseph Lake II 12-13-50-22 W4
Imperial Kinsella 25 10-10-48-12 W4
Imperial Armena 6-IIV 6-11-48-21 W4
Imperial Norbuck 2-6 2-6-47-4 W5
Imperial Joffre 2-21V 2-21-38-25 W4
ALBERTA
SCALE
0 50 MILES 100 150

FIGURE 1.

CHAPTER TWO

STRATIGRAPHY

THE VIKING FORMATION

The Viking formation is an arenaceous succession within the basal portion of the marine Colorado shale group of the Cretaceous system in Central Alberta. The Viking represents only a small portion of the Colorado group (see Stratigraphic Column, page 7) and is below the "fish-scale" marker, how taken as the Upper Cretaceous - Lower Cretaceous boundary (Stelck, 1950), and is above the *Inoceramus* cf *comancheanus* zone (Stelck et al, 1956). A more exact sub-stage for the Viking formation is lower Upper Albian using European terminology.

The Viking formation or its equivalents are found in the subsurface of most of Alberta, southern Saskatchewan, and the northwestern interior of the United States. There is no known outcrop of Viking to the west of the Edmonton area in the foothills of the Rocky Mountains or the Rocky Mountains proper. There are outcrops of Pelican formation (Viking equivalent) along the Athabasca River to the north of the Edmonton area.

The oil - and gas - bearing Viking formation in Central Alberta is approximately 100 feet thick and is an assemblage of marine sands and sandy shales, usually with a grit bed occurring at the top. Thin bentonite beds, ironstone bands, and glauconite are quite common within the Viking formation in this area.

Four wells were used in this study. Using Edmonton as a reference point, two of the wells are thirty miles southeast in the Joarcam field, one well sixty miles southwest in the Keystone area, and the fourth well one hundred miles south in the Joffre oil field.

STRATIGRAPHIC COLUMN

Canadian Superior Morton 9-19

Lsd 9 - Sec.19 - Twp.38 - Rge. 25 W4M.

Depth	
	Lea Park
3490	<u>Top of Colorado group</u> First White Specks
3640	dark to medium grey shale with light buff to white calcareous specks.
	shale - dark to medium grey
4345	Second White Specks same as first white specks
4490	shale - dark to medium grey
4565	Top of the Lower Cretaceous Fish Scale Zone - dark grey shales, sandy, with abundant fish scale remains
4732	shale - dark to medium grey
4868	Viking formation sand, sandy shale and shale in many places topped by a chert pebble member
4955	Joli Fou
5025	dark grey to medium grey shales <u>Blairmore group.</u>
5730	Top of Mississippian

KEYSTONE AREA

Imperial Norbuck 2-6 (Lsd. 2, Sec. 6, Twp. 47, Rge. 4 W5M)

(See Figure 4 and 5)

The Viking formation is 124 feet thick in this area. It overlies 50 feet of Joli Fou shale and is in turn overlain by the Colorado shale. The lithology is mainly arenaceous shale and siltstone with one main sandstone member in the upper half of the section. The main sand is immediately overlain by two thin conglomerate members which are separated by a thin shale member. Four thin bentonite beds are present in the lower half of the section below the main sand member. The main sand member is glauconitic and has ironstone stringers and nodules throughout. Thin lenses of sand and silt above the conglomerates display excellent cross-bedding, and in this area are taken as the top of the Viking formation.

Imperial Norbuck 2-6 is approximately on regional strike with, and 70 miles northwest of, Imperial Joffre 2-21V.

JOFFRE AREA

Imperial Joffre 2-21V (Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M)

(See Figure 6 and 7)

Imperial Joffre 2-21V did not drill completely through the Viking formation, but the discovery well of Joffre (Canadian Superior Morton 9-19 in Lsd. 9, Sec. 19, Twp. 38, Rge. 25 W4M) drilled into the Devonian and is used for a thickness of Viking in this area. The Viking formation is 87 feet thick, overlies 70 feet of Joli Fou shale and is in turn overlain by the Colorado shale. The top of the Viking formation is marked by a grit bed in this area. A thin conglomerate bed occurs a few feet below the grit bed and is separated from the grit by an argillaceous sandstone. The overall lithology is arenaceous shale and siltstone,

with one main coarse sand development. This main sand member is glauconitic and has ironstone bands with limpet-gastropods occurring in the shaly partings. The base of the section is an arenaceous shale which grades into a siltstone just below the main sand member.

Imperial Joffre 2-21V is 65 miles south west of the Joarcam area.

JOARCAM AREA

Imperial Armena 6-11V (Lsd. 6, Sec. 11, Twp. 48, Rge. 21 W4M)

(See Figure 8 and 9)

Imperial Armena 6-11V did not drill completely through the Viking formation, but Imperial Armena 2 in Lsd. 3, Sec. 15, Twp. 48, Rge. 21 W4M drilled into the Devonian and is used for a thickness of the Viking in this area. The Viking formation is 100 feet thick, overlies 80 feet of Joli Fou shale and is in turn overlain by the Colorado shale. The top of the Viking formation is marked by the presence of thin sandstone lenses exhibiting cross-bedding. Three sand members are developed in this well, the uppermost is the main sand development. The sand members are all separated by arenaceous shales and the main sand is glauconitic with a thin bentonite bed at the base. Ironstone bands and a small limpet-gastropod in a shale parting are present in the upper portion of the main member.

Superior Joseph Lake 11 (Lsd. 12, Sec. 13, Twp. 50, Rge. 22 W4M)

(See Figure 10 and 11)

Superior Joseph Lake 11 did not drill completely through the Viking formation, but Superior Joseph Lake 68 in Lsd. 10, Sec. 13, Twp. 50, Rge. 22 W4M drilled into the Blairmore and is used for a thickness of Viking in this area. The Viking formation is 105 feet thick, overlies 60 feet of Joli Fou shale and is in turn overlain by the Colorado shale. Only one good sandstone member is developed in this well with an arenaceous shale member above and below. The main sand is glauconitic and has shaly partings throughout.

CORRELATION OF THE VIKING FORMATION

The general lithology of Imperial Kinsella 25 in Lsd. 10, Sec. 10, Twp. 48, Rge. 12 W4M (See Figure 2) is given below, so that type area Viking formation in the Viking Kensella field may be used for correlation with the Keystone, Joffre, and Joarcam areas. The Viking formation in this well is 44 feet thick and overlies 100 feet of Joli Fou shale (extrapolated) and is in turn overlain by the Colorado shale. The top of the Viking is marked by a thin chert pebble bed. Two shale members occur below the chert pebble bed and are separated by a thin sandstone member which has a bentonite bed immediately above and a chert pebble bed immediately below. Two sandstone members occur below the shale members and are separated by a thin shale member. The uppermost of these two sandstone members is the main sand member while the base of the lower sand member marks the base of the Viking formation.

Imperial Eldorena 1 in Lsd. 4, Sec. 27, Twp. 57, Rge. 20 W4M (See Figure 3) is used to correlate with the Keystone, Joffre, and Joarcam wells used by the writer and with the type area. Eldorena 1 was chosen because of the complete microfossil coverage above, below, and within the Viking formation and the absence of any stratigraphic hiatus (Bullock, 1950). The general lithology of the Viking formation at Imperial Eldorena 1 is somewhat similar to that at Imperial Kinsella 25. In the Eldorena 1 well there are two sandstone developments separated by a shale member. The upper sandstone member has a coarse sandstone developed sixteen feet from the top and probably corresponds to the conglomerate bed developed in the Kinsella 25 well ten feet from the top of the Viking. Below the coarse sand development in the Eldorena well is the main sandstone which corresponds to the main sand in the Kinsella well. The shale member in the Eldorena

IMPERIAL KINSELLA 25
10-10-48-12W4

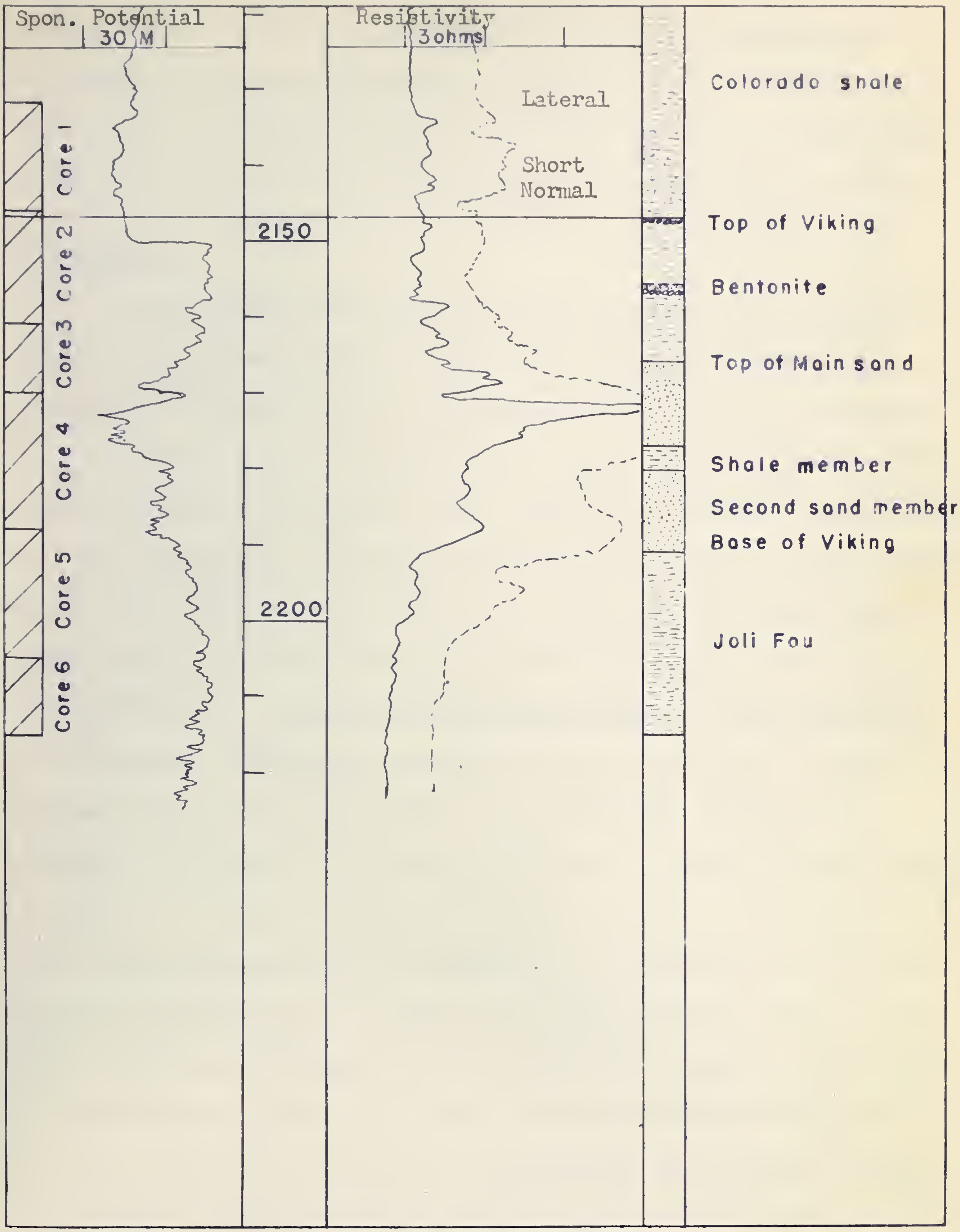

FIGURE 2.

well is underlain by a Second Viking sandstone member which is absent in Kinsella. The thickness of the main or First Viking sand in these two wells is forty four feet at Imperial Kinsella 25 and forty six feet at Imperial Eldorena 1, which would indicate that deposition in the Eldorena 1 well was approximately equivalent to that at Kinsella 25. In Eldorena the underlying Joli Fou shale is cut by two sand members called by Bullock the Second Viking and the Eldorena sand in descending succession.

KEYSTONE AREA

Imperial Norbuck 2-6 in Lsd. 2, Sec. 6, Twp. 47, Rge. 4, W5M was sampled for microfossils and nineteen samples, ranging from immediately above the top to the base of the Viking formation, were studied (See Figure 5). The yield of microfossils was poor but it was felt that a sufficient number of species of Foraminifera was found to correlate with Imperial Eldorena #1. The correlation was started at the top of the Norbuck 1 well, because of the greater abundance of Foraminifera at the top. In five samples from depths 5566 feet to 5578.5 feet (Viking Top 5579 feet, see Figure 5) one species each of Haplophragmoides, Leptodermella, and Verneuilinoides, and two species of Miliammina, were found to be in common with Imperial Eldorena 1 species from depths 1964 feet to 1974 feet. (Viking Top 1980 feet, see Figure 3.) In four samples below the Viking top (at Norbuck) and above the main sand from depths 5581 feet to 5599 feet, one species each of Haplophragmoides linki, Hyperammina, and Miliammina, three species of Haplophragmoides and five species of Ammobaculites were found to be in common with Imperial Eldorena 1 species from depths 1974 feet to 2105 feet. One sample from the base of the Viking formation from depths 5695 feet to 5696 feet contained one species each of Ammobaculites and Haplophragmoides which were found to be the same as species in Imperial Eldorena 1 at a

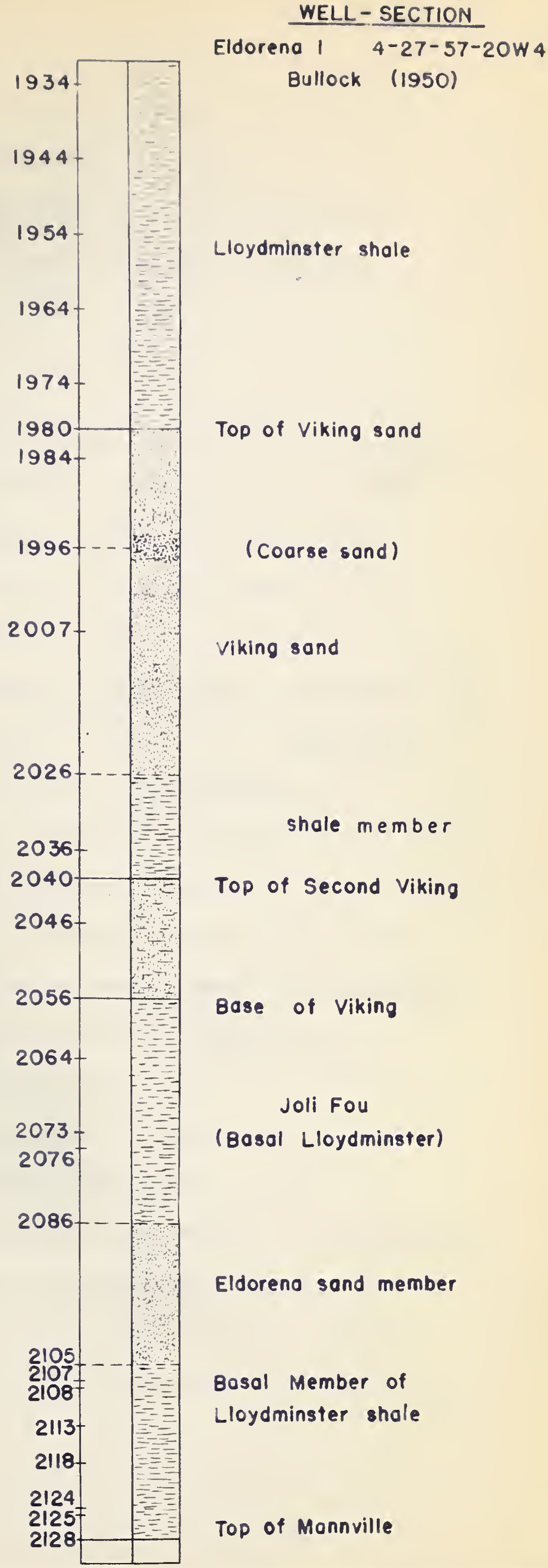
WELL-SECTION
Eldorena I 4-27-57-20W4
Bullock (1950)
1934
1944
1954
1964
1974
1980
1984
1996
2007
2026
2036
2040
2046
2056
2064
2073
2076
2086
2105
2107
2108
2113
2118
2124
2125
2128
Lloydminster shale
Top of Viking sand
(Coarse sand)
Viking sand
shale member
Top of Second Viking
Base of Viking
Joli Fou
(Basal Lloydminster)
Eldorena sand member
Basal Member of
Lloydminster shale
Top of Mannville

FIGURE 3.

depth of 1984 feet. The above correlation indicates that the Viking formation at Imperial Eldorena 1 and the Viking formation at Imperial Norbuck 2-6 were deposited contemporaneously as no time lines appear to have been crossed in going from Imperial Eldorena 1 to Imperial Norbuck 2-6.

JOFFRE AREA

Imperial Joffre 2-21V in Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M was sampled for microfossils and ten samples ranging from immediately above the top to the base of the Viking formation were studied (see Figure 7). Three samples above the top of the Viking formation from depths 4720 feet to 4728 feet (Viking Top 4728 feet, see Figure 7) contained one species each of *Hyperammina*, *Leptodermella*, *Proteonina*, *Reophax*, *Tritaxea*, and *Verneuilinoides*, two species each of *Gaudryina* and *Haplophragmoides*, and four species each of *Ammobaculites* and *Miliammina*, which were also observed in the Imperial Eldorena 1 well from depths 1954 feet to 2026 feet. Two samples were taken below the top of the Viking formation and above the main sand member from depths 4730 feet and 4735 feet. These samples contained one species each of *Ammobaculites*, *Haplophragmoides*, and *Verneuilinoides*, two species of *Miliammina*, collophane spheres and three types of sporomorphs all of which were observed to occur in Imperial Eldorena 1 well between the depths of 1974 feet and 2007 feet. One sample from immediately above the main sand member at a depth of 4754 feet contained one species each of *Ammobaculites*, *Haplophragmoides*, and *Verneuilinoides*, and three types of sporomorphs. These same fossils were seen to occur between the depths 1974 feet and 2046 feet in Imperial Eldorina 1. Four samples were taken in the shale

IMPERIAL NORBUCK 2-6
2-6-47-4W5

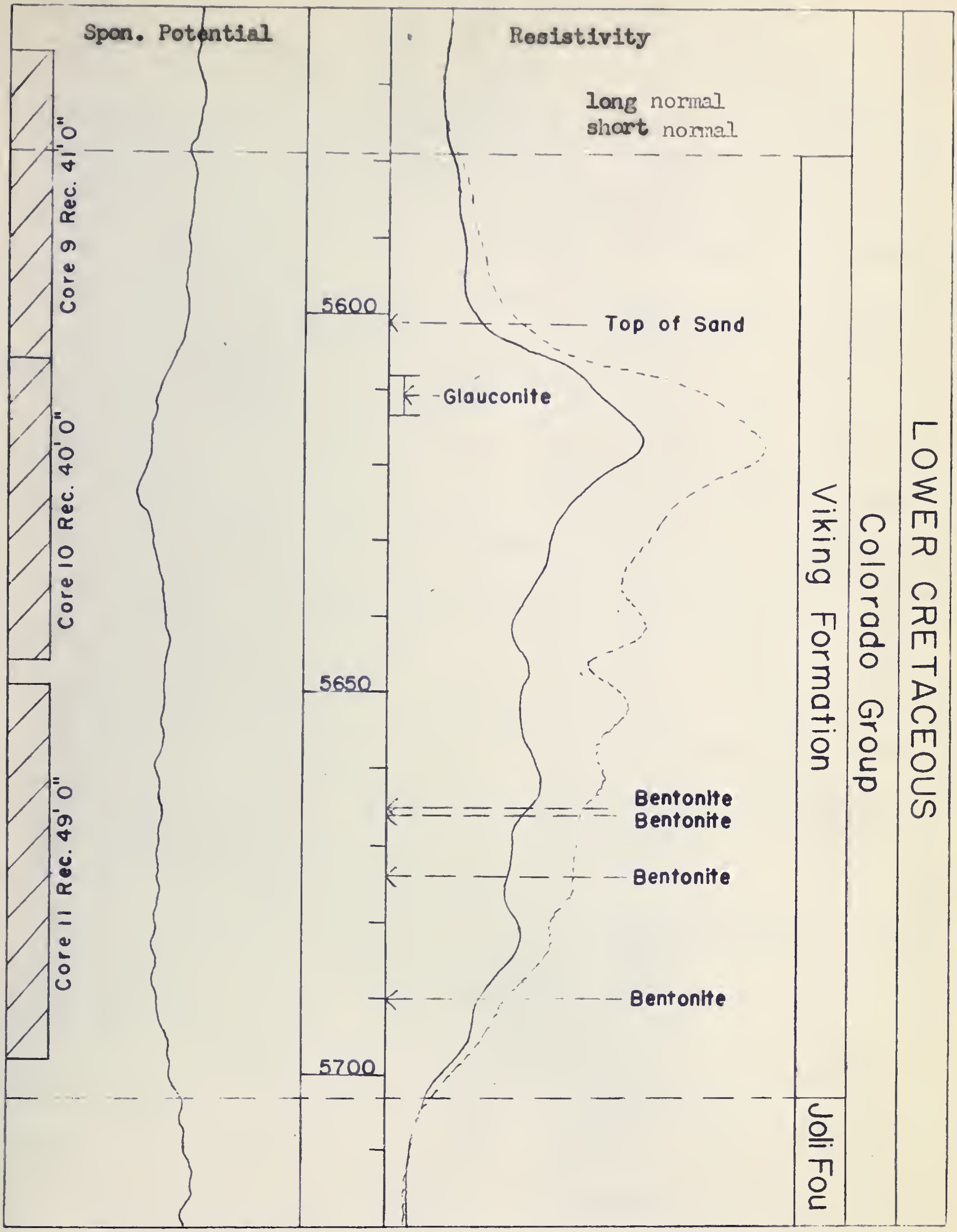

FIGURE 4.

WELL-SECTION

Imperial Norbuck 2-6

2-6-47-4-W5

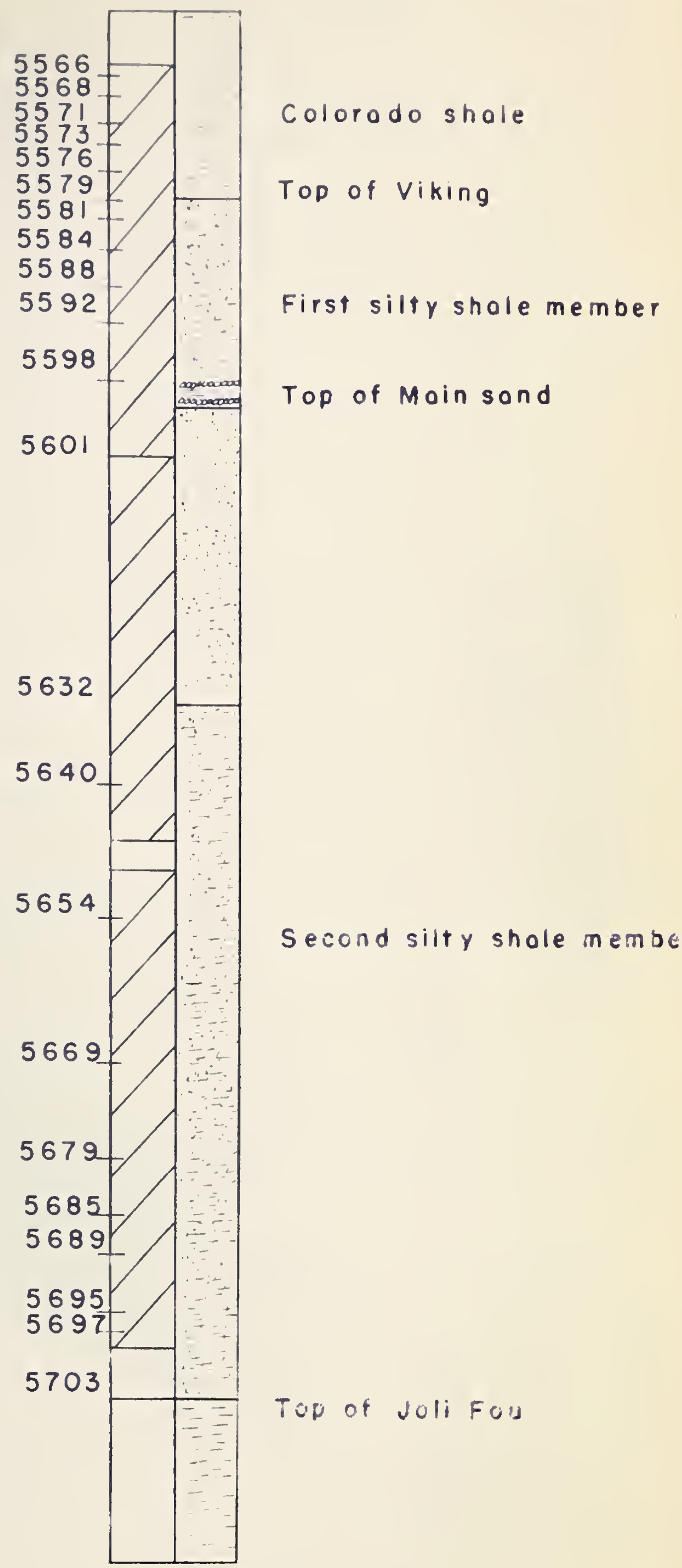

FIGURE 5.

IMPERIAL JOFFRE 2-21V

2-21-38-25W4

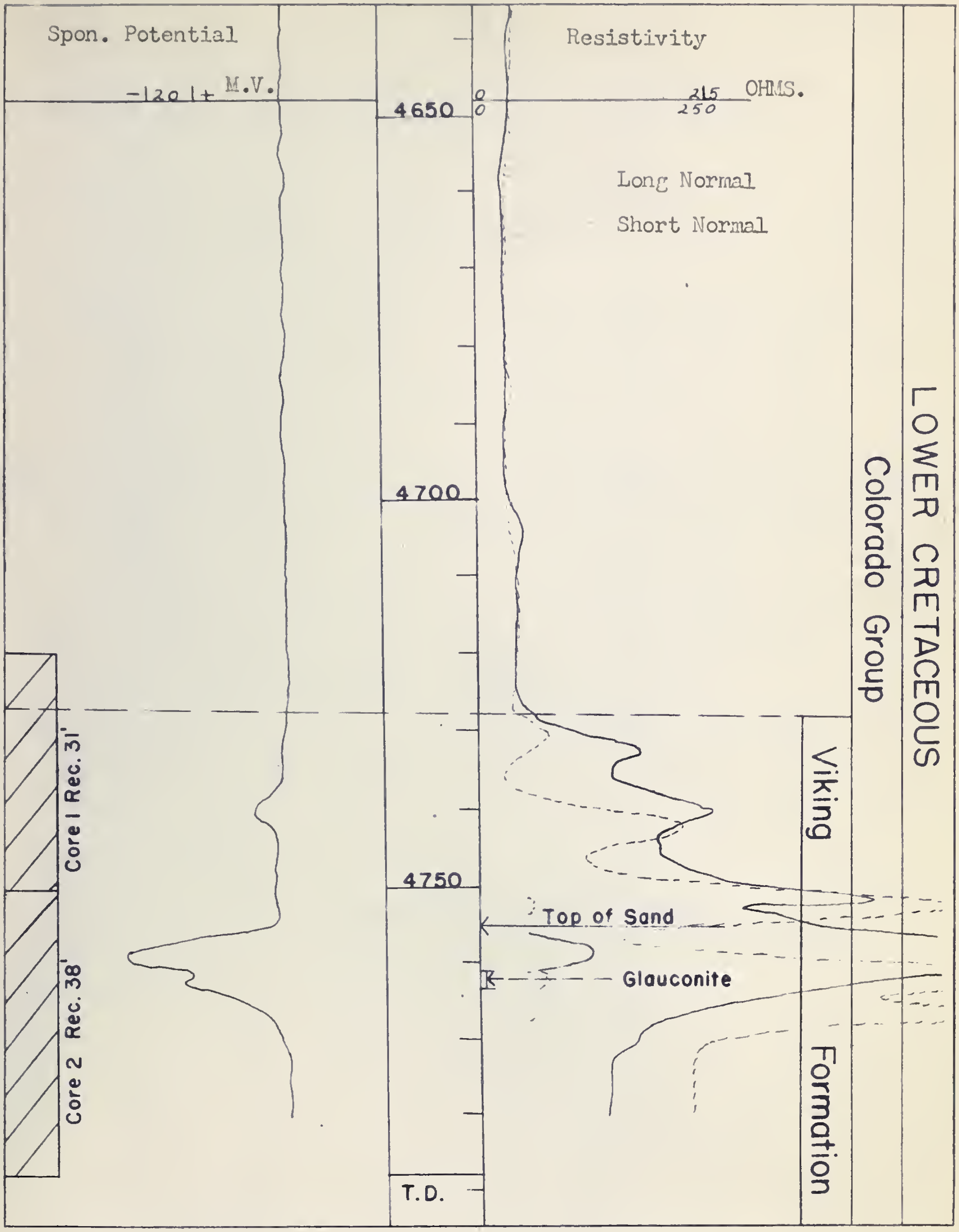

FIGURE 6.

WELL- SECTION

Imperial Joffre 2-21V

2-21-38-25W4

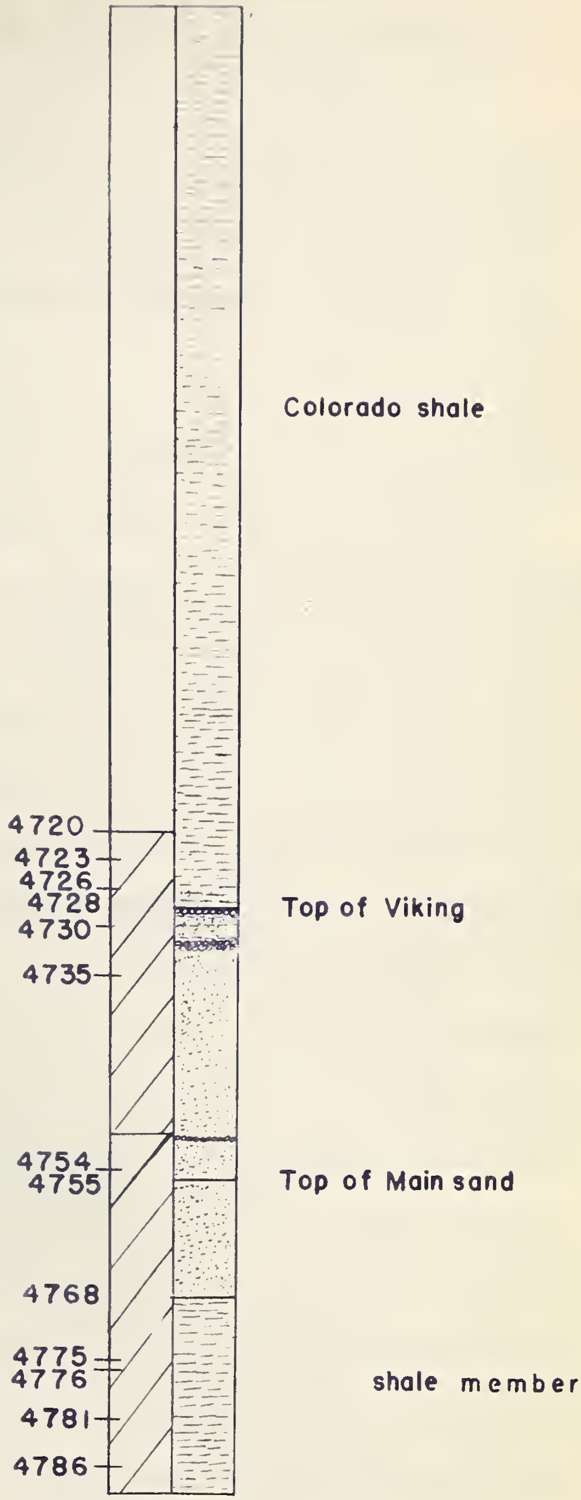

FIGURE 7.

member below the main sand from 4775 feet to 4788 feet and found to contain one species each of Gaudryina, Proteonina, and Verneuilinoides, three species each of Ammobaculites and Haplophragmoides, and three types of sporomorphs all of which also occur in Imperial Eldorena 1 between the depths 1984 feet to 2046 feet.

The correlation between Eldorena 1 and Joffre 1 based on microfaunal evidence shows that there is similar homotaxy in these wells and also that the section at Joffre is complete relative to Eldorena.

JOARCAM AREA

Imperial Armena 6-11V in Lsd. 6, Sec. 11, Twp. 48, Rge. 21 W4M was sampled for microfossils and three samples, two above the main sand and one below were studied. (See Figure 9). The scarcity of samples in this well is because of the silty nature of the shale present and difficulty in separation of microfossils from these silty shales. The uppermost sample taken from 3284 feet to 3284.4 feet did not yield any recognizable microfossils whereas the underlying sample from 3288 feet to 3288.4 feet contained one species each of Ammobaculites and Verneuilinoides, and two types of sporomorphs. These fossils were also observed in Imperial Eldorena 1 at the depths 1974 feet and 1984 feet. The remaining sample was taken from 3333 feet to 3333.4 feet and contained one species each of Ammobaculites, Haplophragmoides, Hyperammina, and Miliammina, and also one sporomorph all of which were found to be similar to species found from 2036 feet to 2056 feet in Imperial Eldorena 1. The above microfaunal evidence indicates that Viking formation in the Armena well and that of the Eldorena well had a similar succession of faunas. This indicates that no time lines were crossed going from one area to the next and thus

IMPERIAL ARMENA 6-11V
6-11-48-21W4

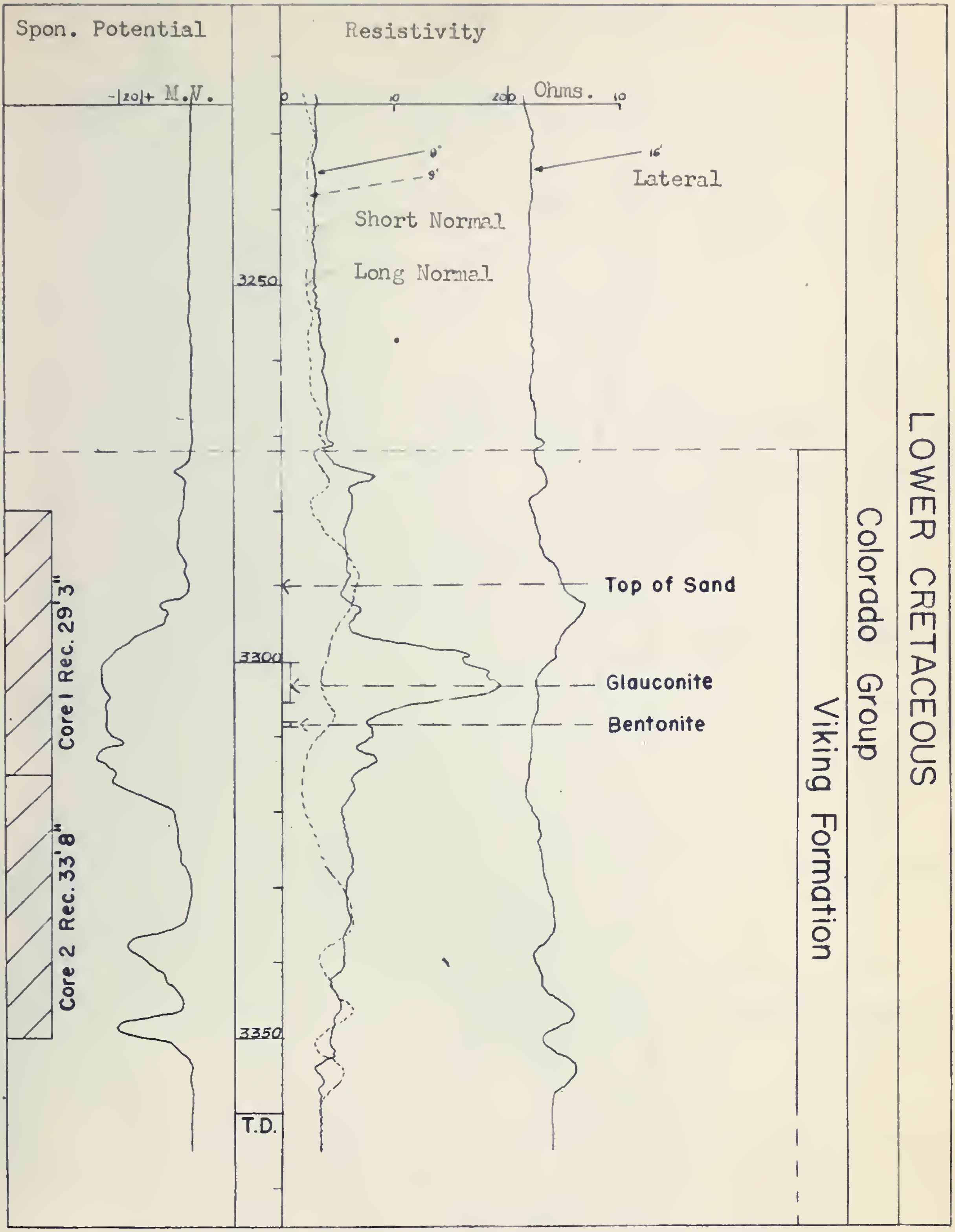

FIGURE 8.

WELL-SECTION
Imperial Armena 6-11 V.
6-11-48-21 W4

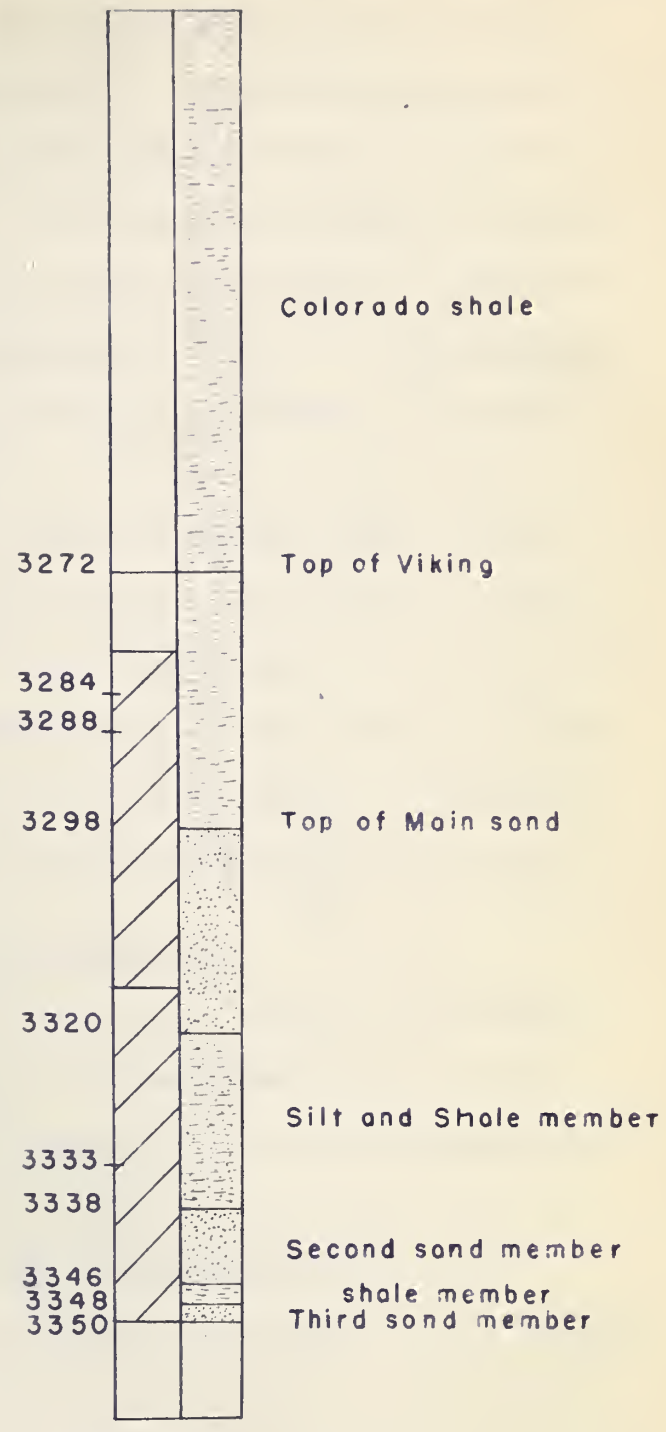

FIGURE 9.

the age of the Viking formation in both areas is the same.

Superior Joseph Lake 11 in Lsd. 12, Sec. 13, Twp. 50, Rge. 22 W4M was also used in the Joarcam area to substantiate the evidence obtained from the Imperial Armena well. Six samples were taken from the Superior Joseph Lake 11 core but unfortunately they all occur below the top of the Viking and above the main sand. (See Figure 11). However, a fairly large suite was recovered and contains collophane spheres, two species of Gaudryina, four species of Haplophragmoides, five species of Ammobaculites, and six types of sporomorphs. These fossils were obtained from depths 3229 feet to 3254 feet (Viking Top 3220, see Figure 11). The same fossils occur in Imperial Eldorena 1 between 1964 feet and 2026 feet in depth. The correlation of microfossils suggests that the upper members of the Viking formation in Superior Joseph Lake 11 correspond to the upper members of the Viking formation in the Imperial Eldorena 1 well. This, of course, substantiates the previous correlation of Imperial Armena 6-11V which is in the same field as Superior Joseph Lake 11 to Imperial Eldorena #1.

CORRELATION OF KEYSTONE, JOFFRE, AND JOARCAM AREAS

The Viking formation in the three areas studied by the writer, using Imperial Eldorena 1 as an outside reference, was found to be the same age. The correlation of these areas was done mainly by Foraminifera with additional correlation on the similarity of sporomorphs within the areas. A limpet-gastropod was observed in Imperial Armena 6-11V at a depth of 3305 feet, near the base of the main sand member. Similar limpet-gastropods were also observed in Imperial Joffre 2-21V at a depth of 4761 feet which is near the base of the main sand member in this well. The appearance of the limpet-gastropods in these two wells at a similar

lithologic position further substantiates the correlation obtained using Foraminifera. Although the Imperial Norbuck 2-6 well has been correlated using Foraminifera, no sporomorphs were observed in the Viking formation in this well. The absence of sporomorphs is interpreted as reflecting a change in environment in the Keystone area relative to the other areas studied. Since the forms present in the Viking formation of the Keystone area are long range types it is therefore difficult to ascertain whether or not the Viking of the Keystone area is mutually co-extensive with that of Joffre and Joarcam.

Depositional Environment

Microfossils, a limpet-gastropod, and certain lithologic and sedimentary features, permit partial reconstruction of the depositional environment of the Viking formation.

The foraminiferal assemblage from the Viking formation is totally arenaceous and the genera suggest deposition in a shallow bay or sound. The absence of calcareous forms in the four areas studied excludes normal open gulf or pelagic deposition. This implies the presence of a shallow landlocked sea or embayment during the deposition of the Viking formation. An analogy to the Viking sea existing today might be Hudson Bay, where a widespread body of almost landlocked shallow marine water exists.

Ecological studies made by Phleger, et al, (Parker, et al, 1953; Phleger, 1954 and 1955) on recent foraminiferal assemblages in the Gulf coast area, serves as a basis for the interpretation of the paleoecology of Viking microfaunal suites. The basic distinction Phleger makes is between an open gulf calcareous fauna and an arenaceous near-shore or sound fauna. In the San Antonio Bay and Mississippi Sound areas the faunas are separated from each other by a barrier of low off-shore islands. During high run-off from the adjoining mainland, and with the presence of the off-shore

SUPERIOR JOSEPH LAKE 11
12-13-50-22W4

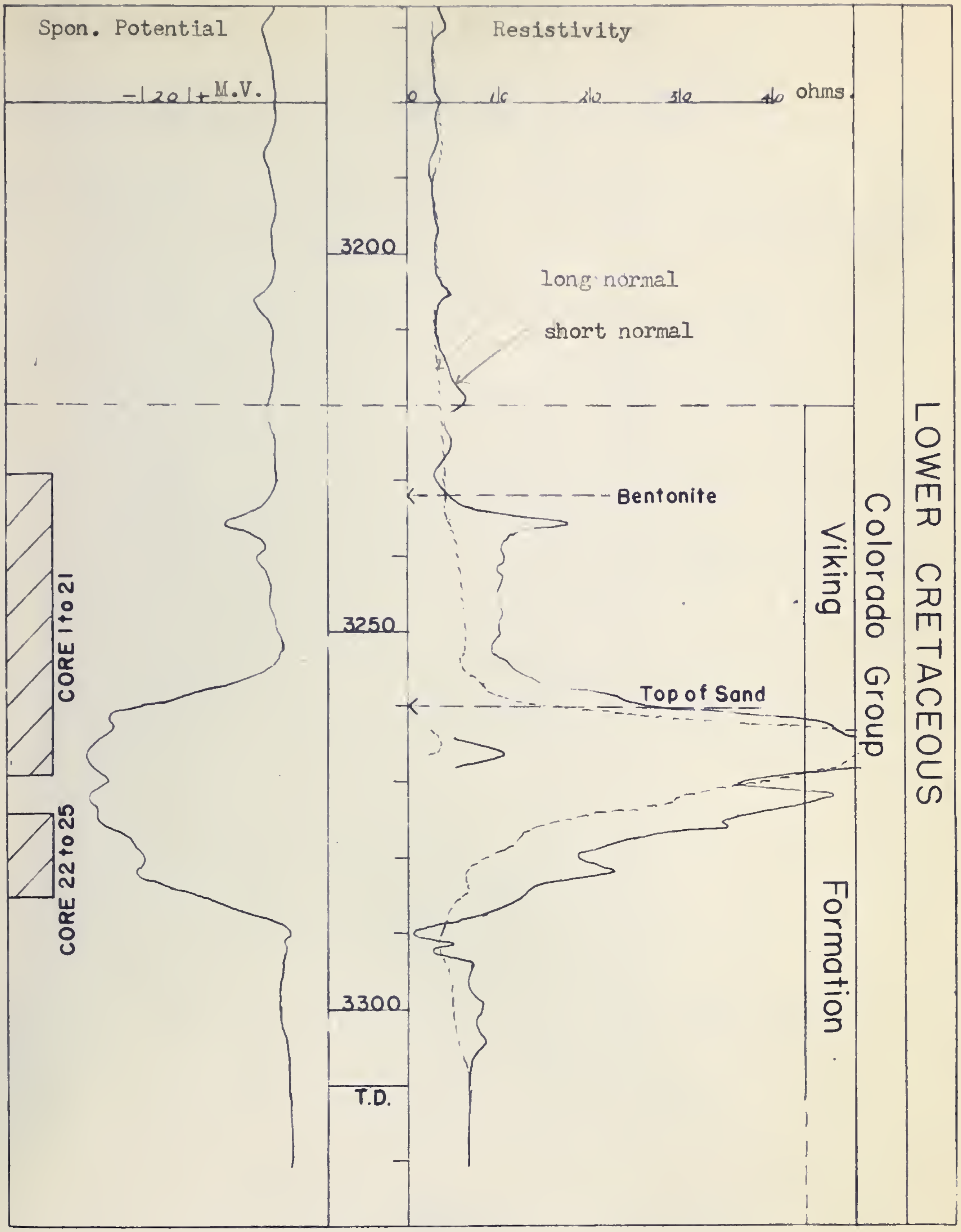

FIGURE 10.

WELL-SECTION

Superior Joseph Lake 11

12-13-50-22 W4

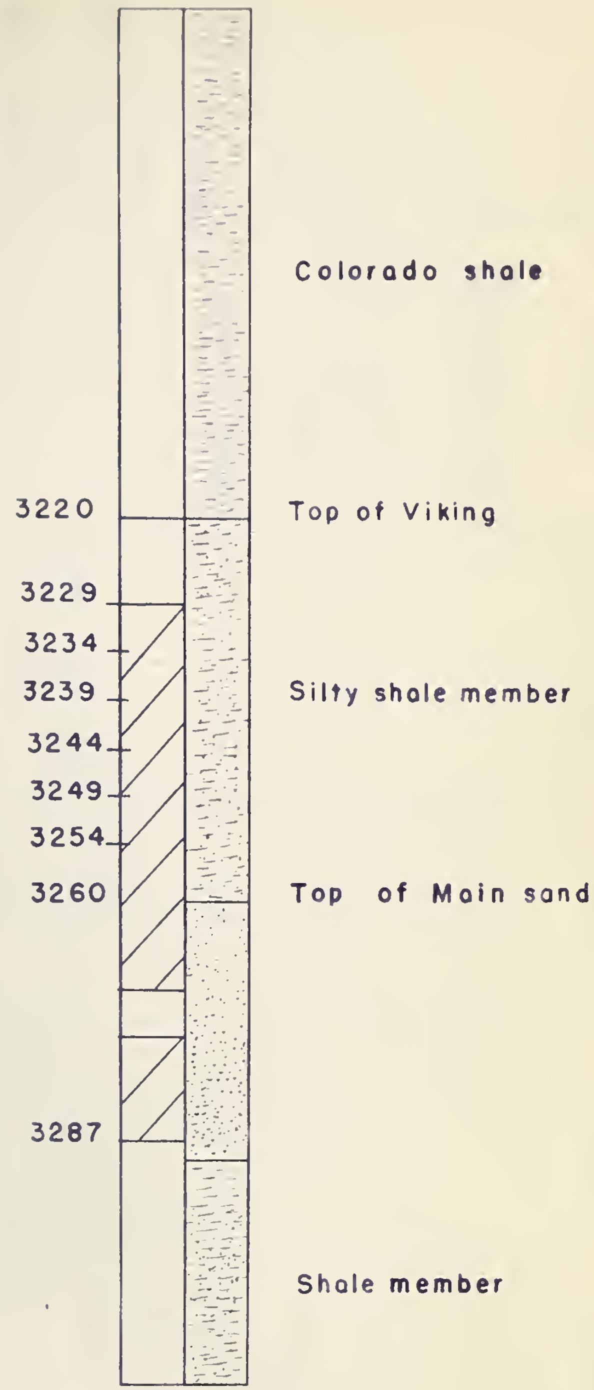

FIGURE 11.

CORRELATION OF LOWER CRETACEOUS FORMATION IN CENTRAL ALBERTA AND ADJACENT AREAS

		Southern Alberta Foothills	Southern Alberta Plains	East Central Alberta	Central Alberta	Central Foothills Cadomin	Lower Athabasca River Area Alberta	Faunal Zone
Upper Cretaceous	Cenomanian	Alberta Shale	Blackleaf Member of Colorado Shale	Lloydminster Shale	Colorado Shale	Blackstone Shale	Labiche Shale	Dunveganoccras Acanthoceras
			Fish	Fish	Scale	Beds		
Lower Cretaceous	Upper Albian	Crowsnest Volcanics	Bow Island	Viking	Viking		Pelican	Neogastroplites
		Upper Blairmore	Shale Member Basal Ss / Joli Fou	Joli Fou	Joli Fou		Joli Fou	Haplo. gigas
	Middle Albian			Mannville			Grand Rapids Clearwater	Gastroplites Lemuroceras
	Pre-Middle Albian	Lower Blairmore Kootenay	Blairmore		"Blairmore"	Mountain Park Luscar Upper Nikanassin	McMurray	Unio biornatus Unio hamili
Underlying Beds		Jurassic	Jurassic	Devonian	Carboniferous	Jurassic	Devonian	

TABLE 1.

islands, the waters of the open gulf are prevented from invading the less saline water of the bay and sound. In periods of low run-off the open gulf waters may invade the areas behind the barrier islands, thus introducing certain elements of the open gulf fauna. The southeastern Mississippi Delta area has no geographic barrier, but an ecological transition zone several miles wide separates the typical sound and open-gulf faunas. The Viking sea in Central Alberta lacks parallels to both Phleger's transition zone and the Gulf facies.

The apparent scarcity of ammonites, not only in the Viking but in the underlying Joli Fou shale, could also be explained by the presence of a partially landlocked sea. This confinement may produce certain environmental conditions which are not favorable to ammonites; e.g. low salinity, muddy waters, or extreme shallowness. One occurrence of an ammonite (Placenticeras) has been reported by Wickenden (1949) from the base of the Pelican sandstone (Viking equivalent along the Athabasca River), which indicates definite though restricted access from the bay area to the open seaway.

The absence of sporomorphs in the Norbuck 2-6 well seems to indicate that a critical ecological change was introduced between Keystone and the Joarcam-Joffre region. A reasonable explanation may be that the Norbuck 2-6 well is close to the shore-line where deposition was more rapid. One might expect that wave action and currents would churn up the sediment making conditions unfavorable for the development of sporomorphs.

The occurrence of limpet-gastropods within the Viking suggests a shallow marine environment. Coupled with the microfaunal assemblage, a maximum depth of 150 feet is postulated.

The presence of glauconite also suggests a rather shallow marine Viking sea. Cloud (1955) states that glauconite most commonly forms either above or below the depositional interface of a relatively shallow marine

body of water in a slightly reducing environment. Such reducing conditions may only be seasonal, cyclic, or intermittent.

The presence of siderite and pyrite in the Viking also indicates reducing conditions near the depositional interface at least intermittently through Viking time. Krumbein and Garrels (1952) show on chemical grounds that certain authigenic mineral suites are the result of rather restricted Eh (oxidation-reduction potential) and pH (acidity-alkalinity) conditions. They show that siderite, glauconite and organic matter should occur together as major constituents in environments with a pH of 7 to 7.8 (alkaline but slightly more acid than normal marine) and an Eh of 0.0 to 0.15 (reducing). It is interesting to note that the glauconite in the Viking formation generally has siderite and thin laminae of black pyritic shale closely associated. The pyrite associated may have formed below the depositional interface where, according to Krumbein and Garrels, the Eh might be lowered and more favorable to the formation of pyrite. It is difficult by petrographic methods to determine whether the glauconite, siderite and pyrite were formed at the depositional interface or below it. Part of the glauconite and siderite present appears to have been moved and redeposited short distances within the basin. If the pH and Eh of the environment varied greatly across the depositional interface, glauconite and siderite formed below the interface and reworked should show some alteration if deposition was slow. There does not, however, appear to be any alteration, which would suggest the glauconite and siderite formed at the interface or that the Eh and pH conditions did not vary much across it. From these data it can be considered that the Viking sea had some periods during which the bottom environment were slightly reducing.

Three samples of Viking shale were checked for total carbon to see if the content was abnormally high. The locations of these samples

are: Armena 6-11V, depth 3291.4 feet, carbon content 2.76 per cent; Armena 6-11V, depth 3295.5 feet carbon content 2.456 per cent; Norbuck 2-6, depth 5594 feet, carbon content 1.79 per cent. The lowest value obtained 1.79 per cent, and the highest, 2.76 per cent, are near the average value of 2.5 per cent as given by Trask (1939) for normal marine near-shore environment. The low concentration found may have been due to a prolonged period of destruction by bacteria and scavenging organisms during abnormally slow clastic deposition, or due to a small organic population in an adverse environment.

The sedimentary features of the Viking formation indicate constant reworking in a shallow sea receiving outside sediments very slowly. The sandy facies are attributed to off-shore bar deposition (De Wiel 1956).

Some writers (Magdich 1955, Beach 1955, 1956) maintain that the Viking formation was deposited by turbidity current action. The writer observed no features requiring deposition by density currents. The absence of deep water benthenic or pelagic foraminifera and the presence only of shallow water forms would indicate normal shallow neritic or litteral depths. The presence of glauconite and siderite, which are considered to be formed in an environment of slow deposition seems to deny the probability of large scale turbidity current action. The regular and paced evolution of faunas throughout Viking time as outlined by Bullock (1950) further indicates a period of slow deposition.

The Viking formation and Joli Fou shale appear to represent continual deposition after the northwestward transgression of the Joli Fou sea. The Viking sea represents a slight retreat followed by a post-Viking westward transgression much greater than the one during Joli Fou time. The retreat of the Viking sea was probably a result of slight uplift in the Blairmore-Kootenay series which then contributed detritus to the Viking sea.

CHAPTER THREE

PALAEONTOLOGY

Collection and Preparation of Samples

The intervals sampled for fossils from the four wells used in this study are listed in the Appendix D.

The writer prepared the samples as follows: approximately half of each sample was placed in a pint sealer, covered with water, labelled and sealed; when the samples had softened sufficiently, they were carefully washed and screened through a set of Tyler screens. The screen set consisted of the following mesh sizes, 28, 48, 80, and 100 mesh to the inch, a collecting pan on the bottom.

The contents of the sealer after a vigorous shaking were emptied on the 28 screen. A small jet of water was directed on the sample until all clay had been washed through. The unbroken residue on the 28 mesh screen was placed in a Waring Blendor (Model PB-5), equipped with a four bladed, light, stainless steel rotor, and the blendor turned on "slow" for two or three minutes (8000 rev./min.). The contents of the blendor were then emptied on the top screen and washed as above. If an appreciable amount of residue still remained it was replaced in the blendor and the process repeated.

The residue on the 48 mesh and succeeding screens was washed by a small jet of water. The clean residue on each screen was transferred to a small saucer and placed in an oven heated to 100°C. The dry samples were placed in screw top glass vials and appropriately labelled.

The dry sample was then poured into a picking tray in such a

manner that a single layer of grains showed up against the blue background. The bottom of the tray is ruled into narrow bands, approximately ¼ of an inch wide. This allows systematic examination of all the particles on the tray.

Picking was carried out under a Leitz binocular microscope. Magnifications of 32 and 48 power were used.

A very fine moistened red sable hair brush (No. 00) was used to transfer the microfossils from the picking tray to the slide. Ten celled slides were used for mounting. Mounting was done on a black matt surface prepared by applying a solution of gum-tragacanth, with a small amount of formaldehyde. The gum was placed directly on the slide and permitted to dry. The moisture on the wet brush softened the gum sufficiently to permit the fossil to adhere to the slide.

Formal Descriptions

Megafossil

Phylum MOLLUSCA

Class GASTROPODA

Genus ANISOMYON Meek and Hayden 1860

Anisomyon sp. aff. A. patelliformis Meek and Hayden

Shell thin, ovate or subelliptic-patelliform, usually broadest towards the posterior or longer side; summit moderately elevated, a little compressed laterally, located in advance of the middle, immediate apex having the generic characters well defined; lateral slopes nearly straight or slightly convex, converging to the apex at an angle of about 90^{o}; anterior slope straight, a little convex or slightly concave; posterior slope convex, and generally showing faint traces of a few

radiating ridges; surface marked by fine, very obscure lines of growth, and indistinct indications of radiating striae. Slight suggestion of occasional pustulations at intersection of ribs and growth lines.

Length of Hypotype: 3.3 mm; breadth 3.2 mm; height 1.67 mm.

Hypotype locality: Imperial Joffre 2-21 in Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M, Depth 4761.3 feet, 33 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontogical Type Collection.

Remarks: This specimen is similar to Anisomyon patelliformis Meek and Hayden (1876, Report of the United States Geological Survey of the Territories, Vol. IX, Plate 18, figs. 5, a, b, c, f). Anisomyon patelliformis differs from this specimen in that the latter has slight suggesting of occasional pustulations at intersection of ribs and growth lines.

Microfossils

Phylum PROTOZOA

Order FORAMINIFERA

Genus AMMOBACULITES Cushman 1910

Ammobaculites 3249

Test medium size, circular in cross-section; early portions close coiled, involute, with three or four chambers, later portion rectilinear, uniserial, consisting of four chambers; inflated; sides very gradually tapering with the greatest width of test made by the last formed chamber; chambers poorly defined in coiled portion, better defined in straight portion, increasing in size as added; sutures rather indistinct, in coiled portion, depressed in straight portion, at right

anlges to long axis of test; wall of sand grains, embedded in siliceous cement, giving a pebbled surface; aperture elliptical, central and terminal, at the end of a pronounced neck.

Length of Hypotype: 0.72 mm.; greatest width 0.36 mm.; diameter of coiled portion 0.2 mm.

Hypotype locality: Superior Joseph Lake 11 in Lsd. 12, Sec. 13, Twp. 50, Rge. 22, W4M, depth 3249 feet to 3254 feet, 29 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontogical Type collection.

Remarks: Appears to be similar to Ammobaculites 8-295C from the upper Buckinghorse formation in northeastern British Columbia (Stelck 1950, Plate 3, Figure 30, 31, 32). It differs from Ammobaculites 8-295C in that there are only 4 chambers in the uniserial portion.

Genus AMMOBACULITES Cushman 1910

Ammobaculites 4776

Test elongate, early portion coiled involute later uniserial, circular in cross-section; chambers four in coiled part, three in uniserial portion; sides very gradually tapering with the greatest width of test made by last formed chamber; chambers poorly defined in coiled portion, better defined in straight portion, increasing slightly in size as added; sutures rather indistinct, especially in coiled portion, depressed, at right angles to long axis of test; wall of sand grains embedded in siliceous cement, giving a fairly smooth surface with surface of grains expressing themselves through the cement finish; aperture obscured believed to be simple, terminal.

Length of Hypotype: 0.51 mm.; greatest width 0.25 mm.; diameter of coiled portion 0.22 mm.

Hypotype locality: Imperial Joffre 2-21 in Lsd. 2, Sec. 21,

Twp. 38, Rge. 25 W4M, depth 4776 feet, 50 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontogical Type collection.

Remarks: This specimen is similar to Ammobaculites tyrrelli (Nauss 1947, Plate 48, figure 2) but is distinguished from the latter by rounded grains in the wall and indistinct sutures, the specimen also lacks an apertural neck.

Genus AMMOBACULITES Cushman 1910

Ammobaculites 4781

Test large, not compressed, cylindrical in cross-section; early portion close-coiled, involute, with four or five chambers, later portion rectilinear, uniserial, consisting of six chambers; sides very gradually tapering with the greatest width of test made by last formed chamber; chambers poorly defined in coiled portion, better defined in straight portion, increasing slightly in size as added; sutures rather indistinct, especially in coiled portion, depressed, at right angles to long axis of test; wall of coarse sand grains, partly embedded in a small amount of siliceous cement, giving a rough, irregular surface; aperture obscured believed to be terminal, central, and simple.

Length of Hypotype: 0.91 mm.; greatest width 0.27 mm.; diameter of coiled portion 0.18 mm.

Hypotype locality: Imperial Joffre 2-21 in Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M, depth 4781 feet to 4786 feet, approximately 50 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type Collection.

Remarks: This specimen is similar to Ammobaculites fragmentarius Cushman variety from the Joli Fou formation (Stelck, et al, 1956, Plate 5,

figure 19) distinguished from the latter by finer grain size, and more distinct sutures on the rectilinear portion.

Genus HAPLOPHRAGMOIDES Cushman 1910

Haplophragmoides cf. linki Nauss

Test rather small, planispiral involute, tiny umbilicus, periphery narrowly rounded, very slightly lobate; chambers distinct, nine in ultimate whorl, gradually increasing in size, sutures indistinct, slightly depressed, nearly radial, slightly convex forward; intercameral walls thickened from partial overlapping of previous chamber; wall finely arenaceous, considerable cement giving a smooth outer finish; aperture obscured believed to be a low arched slit at the base of the terminal face.

Maximum diameter of Hypotype: 0.42 mm.; thickness approximately 0.1 mm.

Hypotype locality: Imperial Norbuck 2-6 in Lsd. 2, Sec. 6, Twp. 47, Rge. 4, W5M, depth 5587.5 feet to 5590 feet, approximately 10 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: This specimen is slightly flattened and pyritized. It differs from Haplophragmoides linki in that the former is more evenly grained, the specimen is thinner, and the chambers are more embracing.

Genus LEPTODERMELLA Rhumbler, 1935

Leptodermella 5587

Test compressed, single chamber, would be plano-convex before compression, now circular in outline with a raised rounded ridge around

border; wall arenaceous with much siliceous cement obscuring sand grains; aperture obscured believed to be simple slight slit slightly arcuate, somewhat depressed in center of the concave ventral face; color buff.

Maximum diameter of Hypotype: 0.34 mm.; thickness approximately 0.1 mm.

Hypotype locality: Imperial Norbuck 2-6 in Lsd. 2, Sec. 6, Twp. 47, Rge. 4, W5M, depth 5587.5 feet to 5590 feet, approximately 10 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type collection.

Genus MILIAMMINA Heron-Allen and Earland, 1930

Miliammina 4730

Test elliptical, slightly compressed; chambers elongate, tubular, each half a turn in length, in quiqueloculine arrangement, three visible on one side, four on the other; sutures indistinct; wall finely arenaceous, considerable cement giving a smooth outer finish; aperture obscured believed to be terminal, at open end of the last formed chamber that projects very slightly beyond the previous chambers; color light buff.

Length of Hypotype: 0.48 mm.; width 0.26 mm.

Hypotype locality: Imperial Joffre 2-21 in Lsd. 2, Sec. 21, Twp. 38, Rge. 25, W4M, depth 4730 feet.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: This specimen shows some relationship with Miliammina manitobensis Wickenden in the quiqueloculine arrangement of the chambers. It differs from Miliammina manitobensis in that it lacks the development of the neck and the noticeably constricted aperture.

Genus VERNEUILINA d'Orbigny 1840

Verneuilina 4786

Test small, short, triserial, roughly triangular in section, edges abruptly rounded; chamber indistinct, very slightly inflated, increasing in size as added, about fifteen in number; sutures indistinct, slightly depressed; wall arenaceous, small amount of silica cement; aperture obscured believed to be an elongate slit at inner margin of last formed chamber; color light buff.

Length of Hypotype: 0.58 mm.; maximum width 0.34 mm.

Hypotype locality: Imperial Joffre 2-21 in Lsd. 2, Sec. 21, Twp. 38, Rge. 25, W4M, depth 4786 feet to 4788 Feet.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: This specimen is slightly flattened.

KINGDOM INCERTAE SEDIS

Sporomorphs - Norris is 1951 described a number of these forms as cutinized micro-fossils. No other formal treatment of these forms is known to the writer.

Sporomorphs 3229

Apparently a small inflated hollowed ellipsoid that has been flattened to a disc-like shape in fossilization. The color is light golden brown and the material is apparently chitinous in composition. No trace of tissue present; the exterior surface has a faintly pebbled texture giving a frosted appearance. There is a slit-like opening along the side about one third of the circumference in length with a cross-tear present only at the one end. Whether this latter feature is due to crushing or pre-diagenetic is difficult to determine. On the one flattened side there are developed wrinkles assumed to be from the flattening; on the other side a subordinate boss is developed of a chevron shape apparently from thickening of the membrane; a comma-shaped depression is developed along the inside of the chevron shaped

boss near

the center of the specimen.

Maximum diameter of Hypotype: 0.33 mm.; thickness approximately 0.03 mm.

Hypotype locality: Superior Joseph Lake 11 in Lsd. 12, Sec. 13, Twp. 50, Rge. 22, W4M, depth 3229 feet to 3234 feet, 9 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: There seems to be a definite organization for dehiscence along the one side. It is suggested that the boss may have been a point of attachment sometime during its history; it lacks the characteristics of a megaspore, it lacks the cellular structure of a sporangium; but it may be an egg capsule from some sort of an invertebrate.

Sporomorph 3239

Apparently a small slightly flattened elongate hollowed spindle that has been further flattened to a narrow leaf shape, pointed at both ends. The color is light golden brown and the material is apparently chitinous in composition. No trace of tissue present. The exterior surface has a faintly pebbled texture giving a frosted appearance. The specimen has a longitudinal axis terminated at both ends by a point. There is a thin strip of thickened membrance down the longitudinal axis which is approximately one-fifth the width of the specimen. This increase in membrane can be seen on both sides of the specimen. A similar though subordinate narrow thickening seems to be present on both margins; this latter feature fails to reach the extremities.

Length of Hypotype: 1.1 mm.; width 0.29 mm.

Hypotype locality: Superior Joseph Lake 11 in Lsd. 12, Sec. 13, Twp. 50, Rge. 22, W4M, depth 3239 feet to 3244 feet, 19 feet below the

top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: It lacks the characteristics of a megaspore, it lacks the cellular structure of a sporangium; but may be an egg capsule from some sort of an invertebrate. They often seem to occur in pairs and some seem to be partially fused. In some cases there is a suggestion of a line of dehiscence parallel and closely associated with the thickened margin.

Sporomorph 3249

Apparently a small slightly flattened hollowed spindle that has been further flattened to a narrow leaf shape, pointed at both ends. The color is light golden brown and the material is apparently chitinous in composition. No trace of tissue present; the exterior surface has a faintly pebbled texture giving a frosted appearance. The specimen has a longitudinal axis terminated at both ends by a point. There are two thin strips of thickened membrane down the longitudinal axis which are approximately one-fifth the width of the specimen. The two strips occur approximately there own width distance in from the margin meeting at each end of the longitudinal axis. The increase in membrane can be seen on both sides of the specimen. There appears to be fine longitudinal striations approximately twelve in number to a side. There is a definite longitudinal slit which may be evidence of dehiscence along one side between the two longitudinal thickenings and offset from the center thus being closer to one of the thickenings.

Length of Hypotype: 1.18 mm.; width 0.40 mm.

Hypotype locality: Superior Joseph Lake 11 in Lsd. 12, Sec. 13, Twp. 50, Rge. 22, W4M, depth 3249 feet to 3254 feet, 29 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: It lacks the characteristics of a megaspore, it lacks the cellular structure of a sporangium; but may be an egg capsule from some sort of an invertebrate.

Sporomorph 4735

Apparently a small inflated hollowed spindle that has been flattened an oval shape in fossilization. The color is light golden brown and the material is apparently chitinous in composition. No trace of tissue present. The exterior surface has a faintly pebbled texture giving a frosted appearance. The specimen appears to have a long axis terminated at each end by a blunt angulation. There is a slit-like opening on one side which is central and along the long axis. On the side with an opening there is an extra layer of material over half the surface. On the other side there are wrinkles assumed to be from the flattening. There is a tear along the margin about one fifth of the circumference located at one end on the half with the extra layer of material. This tear appears to be due to crushing.

Length of long axis of Hypotype: 0.53 mm.; length of short axis 0.38 mm.

Hypotype locality: Imperial Joffre 2-21V in Lsd. 2, Sec. 21, Twp. 38, Rge. 25, W4M, depth 4735 feet, 7 feet below the top of the Viking formation.

Hypotype: University of Alberta Palaeontological Type collection.

Remarks: There seems to be a definite organization for dehiscence on the one side; it lacks the characteristics of a megaspore, it lacks the cellular structure of a sporangium; but may be an egg capsule from some sort of an invertebrate.

CHAPTER FOUR

PETROGRAPHY

General Description

Cores from three wells were used for the study of thin sections from the Viking formation. Imperial Norbuck 2-6, Imperial Armena 6-11V, and Imperial Joffre 2-21V were sampled and thirty-three thin sections were prepared. Eight of these sections were prepared by Booklime Incorporated in Salt Lake City, the samples all being from Imperial Joffre 2-21V. These thin sections were not impregnated and consequently are very poor. The remaining twenty-five thin sections were prepared by G. S. Rev in New York, eleven from Imperial Norbuck 2-6 and fourteen from Imperial Armena 6-11V. The thin sections prepared by G. S. Rev were impregnated and are of very good quality.

In sampling the core from these three wells for thin-sectioning, shales were not selected. The writer felt that not enough critical petrographic information could be obtained from the shales to warrant sectioning.

A general description of the thirty-three thin sections is given below. The detailed description of each thin section is in Appendix B.

The grain size varies from medium siltstone to fine pebble conglomerate. The grade scale used was that published by the National Research Council (1947).

The grains vary in roundness from angular to rounded with the majority of sand grains being subrounded to subangular. The siliceous rock fragments are, for the most part, more rounded than the associated quartz grains.

Packing of the grains was generally found to be tight (initial porosity less than 25%), but in some cases normal and loose packing (initial porosity greater than 35%) were observed. Packing plus subsequent cementation controls the porosity, which in most cases is very low. Porosity from 5% to 30% occurs in medium to fine sandstone in Imperial Armena 6-11V. Norbuck 2-6 samples are all tightly packed and porosities are less than 1%. Although Imperial Joffre 2-21V had observable porosity in hand specimens, it was impossible to estimate porosity from the thin sections because the rock was badly pulled apart.

Cementation in the Viking formation is mainly silica in the form of quartz overgrowths. Occasional zones contain authigenic calcite. All three wells have minor calcite cement present with more abundant silica cement. One thin section from the top of the Viking formation in Imperial Joffre 2-21V had a high percentage of calcite cement and no silica cement.

The sorting ranges from very good to poor in all three wells. There are approximately the same number of well sorted, medium sorted, and poorly sorted samples in the thin sections used. However, it is noteworthy that the greatest percentage of well sorted sandstones come from the Imperial Armena 6-11V well which is geographically allied to a large oil producing trend.

The main minerals found in these sections were quartz and siliceous rock fragments. The quartz is generally rounded but may have authigenic overgrowths producing euhedral crystals. Small liquid and solid inclusions were observed in some of the quartz grains but the solids were too small to determine petrographically. The siliceous rock fragments are mainly chert and argillite fragments with minor amounts of quartzite

and siliceous volcanic fragments. Some of the chert grains have definite organic structures, some of which appear to be sponge spicules. This may suggest that the Mississippian to the west, which contains chert, rich in organic matter, contributed to the Viking sea. The roundness of the larger chert grains, however, indicates a long period of abrasion distributed perhaps over more than one cycle. The quartz and rock fragments quite often have a matrix binding them. This matrix is composed of very fine silt and illitic clay which sometimes has carbonaceous and pyritic material scattered throughout. Siderite bands are common within the Viking formation and in some thin-sections make up almost the complete slide. The petrographic determination of the siderite was substantiated by an x-ray diffraction pattern which was run on one of the samples. Some of the siderite occurs as sand size grains along with quartz and rock fragments and appears to be clastic. It has probably been derived, however, from within the basin. Animal burrows appear to have been made through the siderite, suggesting that it was unconsolidated and near the depositional surface at the time of emplacement. Minor amounts of glauconite were observed in most thin sections, but the main glauconitic zones were sampled for potassium-argon dating and heavy mineral studies and were therefore not used for thin sections. P.J.S. Byrne of the Research Council of Alberta did x-ray diffraction work on two glauconite samples to verify the petrological determination. One of the glauconite samples was from Imperial Joffre 2-21V the other from Imperial Armena 6-11V. He found that the glauconite from the Viking formation is composed of interlayed clay materials, illite and a montmorillinite type structure that exhibits a swelling lattice. The glauconite crystal structure was found to be well ordered (it shows no evidence of random displacement

in the a-b plane). Minor amounts of clastic collophane were also noted throughout most of the sections. The petrographic determination of collophane was verified by an x-ray diffraction pattern which was found to be similar to apatite. Feldspar is almost lacking in the eastern wells although some alkali feldspar was identified. Twinned plagioclase increases in percentage at Imperial Norbuck 2-6 and suggests that the source is closer to this well which is the western-most well used.

Several structures were observed in thin sections as well as in cores. Cross-bedding on a minor scale was found to generally occur near the top of the Viking formation, whereas cut and fill and reworking of the sediment were observed lower in the section. Graded bedding was observed only in a four-inch band of coarse sandstone from Imperial Joffre 2-21V. Vertical fractures in the silty and shaly portions towards the base of the Viking formation appear to be quite common.

Heavy Accessory Minerals

General Statement

Heavy minerals from the Viking formation were obtained from four wells. Six samples were taken using one-quarter of the core cut vertically through the sampled zone. One sample is from Imperial Norbuck 2-6 from a depth of 5608 feet to 5613 feet. Two samples are from Imperial Joffre 2-21V, one from 4756.3 feet to 4757 feet and the other from 4761.3 to 4763.4 feet. Two samples are from Imperial Armena 6-11V, one from 3300.6 feet to 3305.4 feet, and the other from 3338.3 feet to 3340.5 feet. One sample is from Superior Joseph Lake 11 and covers two intervals, 3260 feet to 3268 feet and 3274 feet to 3284.5 feet. All samples are

from the main sand development except the second last sample which is from the second sand at Armena 6-11V. The samples were gound fine enough to go through a 16 mesh screen. They were then wet sieved using 5, 10, 16, 35, 45, 60, 80, 120, 170 and 200 mesh screens (U.S. Series). The fraction retained on the 170 mesh screen was dried and saved for heavy mineral separation.

To separate the heavy minerals from the light minerals, an apparatus consisting of two long-stemmed two-inch diameter funnels, rubber tubing, pinch clamp and stand were used. One funnel, fitted with approximately two inches of rubber tubing and clamp on the end of the stem, was set up above the second funnel. The upper funnel was partly filled with tetrabromoethane ($CHBr_2$ $CHBr_2$) having specific gravity of 2.950/20°C. About 10 grams of a washed and dried sample was poured into the tetrabromoethane and stirred occasionally until all the heavy minerals in the sample settled out in the stem of the funnel. The heavy mineral grains were allowed to flow out of the funnel stem by releasing the pinch clamp on the rubber tubing, and were collected on filter paper in the lower funnel. The filter paper containing the heavy minerals was removed and the light minerals were washed out of the upper funnel onto another piece of filter paper. Both the light and heavy minerals were washed with acetone to remove all tetrabromoethane and then dried.

Prior to the mounting of the heavy minerals in Aroclor ($n = 1.66$), a check for the presence of iron grindings and magnetite was made by use of a magnet. Only a little magnetite was present.

An examination of two slides from each interval sampled was made. The slides were placed on a mechanical stage and traverses were

made across the slide. All the non-opaque minerals were recorded and an equal number of opaques were recorded. The number of opaques plus siderite and collophane greatly exceeded the remaining minerals present and negated the significance of any statistical count. The relative abundance of the heavy accessory minerals for each of the six samples used is tabulated in Table 2 (page 52). Microphotographs of some of the heavy minerals present in the Viking formation are shown in Plate 8 and Plate 9.

List of Heavy Accessory Minerals

Authigenic

Pyrite

Detrital

Anatase
Apatite
Biotite
Brookite
Chlorite
Chloritoid
Collophane
Garnet
Hornblende
Ilmenite
Leucoxene
Magnetite
Monazite
Rutile
Siderite
Sphene
Tourmaline
Zircon

Description of Opaque Heavy Minerals

Ilmenite - Irregular grains exhibiting a grey to pinkish-purple lustre in reflecting light. This mineral is also distinguished from magnetite by its lesser magnetism and common association with leucoxene. Sources

are mainly igneous rocks especially more basic varieties such as gabbros and diorites.

Leucoxene - Occurs as rounded, white to yellowish-white dull grains often having a rough, pitted surface. It is derived from ilmenite and quite often the grains have an ilmenite core.

Magnetite - Present as small angular grains and/or faceted octahedral and dodecahedral grains; identified by its magnetic property and silver grey to black lustre in reflecting light. Magnetite occurs widely distributed in grains in igneous rocks, being most abundantly found in the ferromagnesian-rich rocks.

Pyrite - Occurs most commonly as irregular grains made up of clusters of cubic, dodecahedral or octahedral crystals; in some cases as aggregates of small micro-spheres in pinpoint size clusters. Microfossils completely or partially replaced by pyrite were found and collected.

In most slides limonite - coated chert and quartz grains were found. This limonite is believed to be due to oxidation of pyrite grains attached to the chert and quartz grains. The quantity of pyrite and limonite on the chert and quartz was large enough to raise the specific gravity over 2.95. The pyrite is believed to be authigenic.

Description of Non-Opaque Heavy Minerals

Anatase - Pale yellow, tabular, turbid appearance; high refractive indices, and high birefringence. Possible source is some granite-pegmatites, though it may be authigenic.

Apatite - Colourless, some grains have a distinct brown rim and dark inclusions; angular to rounded, most grains are subangular, which may be partly due to crushing; characterized by its low birefringence and

by the uniaxial negative figure of the basal section. Possible sources are igneous rocks and metamorphic limestones.

Biotite - Greenish-brown to dark brown; occurs as angular flakes which may or may not have small inclusions which are probably zircon. Sources are igneous and metamorphic rocks.

Brookite - Brownish-yellow, weakly pleochroic, occurs as tabular grains with marked striations parallel to the length; high indices of refraction and high birefringence. Possible sources are acid igneous rocks and crystalline metamorphic rocks. It may also be authigenic.

Chlorite - Green, subangular to subrounded grains with micaceous habit, weak birefringence. The source may be an alteration of various ferromagnesian minerals.

Chloritoid - Light greenish-blue; occurs as angular micaceous flakes. The mineral has a higher refractive index than chlorite, with which it is often confused. The source may be low-to medium-rank metamorphic rocks.

Collophane - Color varies from yellow to brown to almost black; may show haversion canals and lacunae as dark lines and dark spots; isotropic in most cases but may be slightly anisotropic. An x-ray diffraction photo was taken of this mineral and found to compare closely to that of apatite. The source may be organic structures within the sediment.

Garnet - Pale pink (Almandine) or colorless grains, irregularly shaped, optically isotropic. Sources of garnet are igneous and metamorphic rocks, particularly crystalline gneisses and schists.

Hornblende - Green and only weakly pleochroic; prismatic cleavage is distinct; grains are angular. Sources of hornblende are acid and inter-

mediate igneous rocks.

Monazite - Yellowish brown, pleochroism faint or lacking; subrounded grains with high refractive indices and birefringence. Source is acid igneous rocks.

Rutile - Dark brown to yellowish brown, pleochroism faint; grains are subangular to subrounded; extreme indices of refraction and birefringence. The source may be acid igneous rocks or crystalline metamorphics.

Siderite - Color varies from almost clear to dark brown; grains are mainly angular, some being subangular; high refractive indices and high birefringence; it is uniaxial negative. The identification of this mineral was checked by x-ray diffraction. Source may be clay iron-stone bands or concretions within the basin.

Sphene - Light brown to colorless; some grains are subangular others euhedral; high indices of refraction; high birefringence, and very strong dispersion. Source may be acid and intermediate plutonic igneous rocks, also schists and gneisses.

Tourmaline - Predominating colors are greens to various shades of brown; a minor number of colorless, pinkish, light green and blue varieties also occur; grains range from euhedral to well rounded, the majority being well rounded; grains show marked pleochroism. The predominent types are green, pleochroic to pale brown or pale pink, and green, pleochroic to darker green; other varieties are rare. Commonly a near-basal section of the green variety is seen showing maximum adsorption and minimum pleochroism, the change of color going from dark green to nearly black. This orientation invariably gives a slightly off-centre uniaxial figure. Two green grains were observed with clear authigenic overgrowths on one end. The overgrowths had been rounded by abrasion.

Krynine (1946) listed five main sources of sedimentary tourmaline:

(1) Granitic tourmaline; dark brown, green, or pink (with a greenish cast); frequently full of bubbles and inclusions.

(2) Pegmatitic tourmaline; blue, with pleochroism in shades of mauve and lavender; inclusions are rare.

(3) Tourmaline from metamorphic rocks; in pegmatized sandstone, pale to deep brown, poor in inclusions; in slates, phyllites, and non-quartzose mica-schists, colorless to very pale brown, frequently full of black carbonaceous inclusions if the injected phyllite was originally a dark or black shale.

(4) Sedimentary authigenic tourmaline, occurring as colorless overgrowths on detrital grains; show polar development at one end only of the c-axis; overgrowths may develop on brown, blue, green, yellow, or black cores.

(5) Reworked tourmaline from older sediments; any of the four primary sources that has been reworked.

Krynines first four types are all varieties of primary tourmaline derived from the parent rock as first cycle detrital grains. Most of the tourmaline in the Viking is so well rounded as to indicate more than one cycle of working, corresponding therefore to Krynines type 5. However, all of the primary sources are represented, though granitic and metamorphic terranes were the predominant sources.

Zircon - Usually colorless, with only the occasional purple (hyacinth) variety; colorless variety generally rounded, though some euhedral grains were observed; hyacinth zircons are well rounded and suggest more than one cycle of erosion; many colorless zircons contain prismatic

and liquid inclusions which are irregularly orientated relative to the crystal axis of the grains.

The euhedral, subhedral and angular zircon grains are probably derived from acid and intermediate igneous rocks while the rounded grains come from reworked sediments. The rounded hyacinths are probably derived from reworked sediments that had Pre-Cambrian rocks as one source.

RELATIVE ABUNDANCE OF HEAVY ACCESSORY MINERALS

Heavy Minerals	Joffre #1 *	Joffre #2 *	Joe. Lake #1 *	Norbuck #1 *	Armena #1 *	Armena #2 *
Authigenic						
Pyrite	A	A	A	A	A	A
Detrital						
Anatase				Tr		
Apatite		R	A	A	R	A
Biotite		Tr	R	R	R	R
Brookite					Tr	
Chlorite		Tr	Tr			Tr
Chloritoid	R	R	Tr	Tr	Tr	Tr
Collophane	A	A	A	R	A	A
Garnet		Tr	C	R	R	C
Hornblende		R		Tr		
Ilmonite	R	R	R	R	R	R
Leucoxene	C	C	C	R	C	C
Magnetite	C	C	C	C	C	C
Monazite				Tr		
Rutile		Tr	Tr			
Siderite	A	A	A	A	A	A
Sphene			Tr	Tr		
Tourmaline		R	A	C	C	A
Zircon	R	C	A	A	R	A

A = abundant C = common R = rare Tr = trace

* Location of Samples in Appendix C.

TABLE 2.

[illegible]

CHAPTER FIVE

Geochronology

Introduction

Age dating was undertaken with a two fold purpose; first, to aid in determining the source of the bentonitic ash beds, secondly to establish an absolute age for the Upper Cretaceous - Lower Cretaceous boundary. The presence of glauconite and bentonitic ash beds within the Viking formation in Central Alberta provides an opportunity to obtain an age by the potassium - argon method. The source of the bentonitic ash beds would necessarily be igneous extrusives of the same age as the Viking formation and would exclude extrusives of older and younger ages.

Collection and Preparation of Material

The glauconite and bentonitic ash were collected from Imperial Armena 6-11V core at depths of 3300.5 feet to 3305.4 feet and 3308.9 feet to 3309.1 feet respectively.

The cored interval containing the glauconite was mechanically crushed until it would pass through a 10 mesh screen. The disaggregated sample was put through a series of sieves consisting of the following screen sizes, 10, 16, 35, 45, 60, 80, 120, 170, and 200 meshes to the inch (U.S. Sieve Series). The material on the 16 mesh and finer screens was washed by a small jet of water until all clay material had been washed through. The clean residue on each screen was transferred to a saucer and dried in an oven heated to 105°C.

The dry sample retained on the 45 mesh screen was separated into different magnetic fractions using a Frantz Isodynamic Magnetic Separator.

The strongly magnetic fraction was previously removed from the sample by means of a hand-magnet. Two current strengths were used, 0.35 amps and 0.65 amps. The setting of the Frantz separator was constant at a slope of 15 degrees and a tilt of 8 degrees. A setting of 0.35 amps effectively removed all the minerals which were more magnetic than glauconite except some siderite. The Frantz separator was then run at 0.65 amps whereby most of the glauconite was separated from the rest of the sample. The above procedure was repeated several times to obtain a purer sample.

The glauconite sample still contained siderite which was removed by a heavy liquid separation. The separation procedure is the same as that described in Chapter Four (page 45) for heavy minerals. Tetrabromoethane (S.G. 2.95) and acetone were mixed to give a specific gravity of 2.66. The two liquids were mixed with a piece of quartz in a container until the quartz (S.G. 2.66) just floated. When the sample was placed in the liquid, glauconite floated and the siderite sank to the bottom of the separatory funnel. The glauconite was then washed several times with acetone to remove the tetrabromoethane.

The bentonitic ash was simply crushed until it would pass through a 35 mesh screen.

Samples of glauconite and bentonitic ash were analyzed for potassium using a Perkin-Elmer Model 146 Flame Photometer with lithium as an internal standard.

Samples of glauconite and bentonite, each of weight ten grams were forwarded to S. S. Goldich at the University of Minnesota for physical age determination by the potassium-argon method.

Results

The writer obtained values of 5.11% K_2O and 5.107% K_2O for the glauconite sample with a 0.4 gram sample. The potassium analysis by the Minnesota laboratory on glauconite yielded a value of 4.96% K_2O. Determinations were run of the bentonitic ash for potassium content and values of 1.515, 1.504, 1.48, and 1.496% K_2O were obtained. These values agree very closely with the gravimetric value obtained by the Minnesota laboratory which was 1.48% K_2O.

The uncorrected potassium-argon age determinations received from the University of Minnesota are 63 m.y. (million years) for the glauconite and 45 m.y. for the bentonite. These determinations were done by Baadsgaard of the University of Minnesota.

Results from four other potassium-argon age determinations by Baadsgaard have been received at the University of Alberta. Three are for mid-Cretaceous intrusions, the fourth is an anorthoclase grit from the top of the Upper Cretaceous. The location of the samples dated are:

(1) Sirdar Batholith, British Columbia
Dated at 82 m.y.
Longitude 116° 40' West, Latitude 49° 50' North

(2) Itsi Batholith, Yukon
Dated at 102 m.y.
Longitude 130° 00' West, Latitude 63° 00' North

(3) Coast Range Batholith, British Columbia
Dated at 105 m.y.
Longitude 123° 15' West, Latitude 49° 20' North

(4) Ardley seam, Alberta
Dated at 52 m.y.
Longitude 113° 12' West, Latitude 52° 19' North

The above dates are all plotted on Holmes B Time Scale (see figure 12). All dates (K/A) plotted on this Time Scale were calculated

using a 0.117 branching ratio (Cormier, et al., 1956).

Interpretation

The two values received as an absolute age for the Viking formation are distinctly low when compared to its stratigraphic position and correlation based on palaeontological evidence. The Viking age dates have been plotted on the Holmes' B Time Scale as being not later than lowest Cenomanian. However the discrepancy in the calculated physical age and the palaeontological age is still marked. A possible source of error is argon leakage or adsorption of potassium in the structures. The possibility of potassium adsorption is strong, as x-ray determinations have shown both the glauconite and the bentonitic ash have lattice swelling structures. The bentonitic ash is composed entirely of montmorillonite, whereas the glauconite has a well-ordered illite-montmorillinite mixed layer structure. The samples were obtained from a porous horizon and there is the possibility that migrating solutions affected these clay structures during diagenesis. The bentonite with its montmorillonite structure is probably more susceptible to change than the glauconite, which might account for the 18 million year difference in age determinations between the two. Lipson's work on Cretaceous and Tertiary glauconites gives age dates that show a marked tendency to be younger than the sediment actually is. (Lipson, 1956) If a correction is applied to his dates so they fall on Holmes Time line, one finds approximately a 30% increase required using the calculated age. If a similar correction were to be applied to the glauconite sample from the Viking, an age of approximately 80 million years would

be obtained. This age would seem to be more in agreement with palaeontological evidence.

The physical ages on intrusives from southeastern British Columbia (Nelson Batholith) to the Yukon (Itsi Batholith) indicate a major period of igneous activity in Mid-Cretaceous time. This major period of activity started about 100 million years ago and continued on intermittently throughout Cretaceous time. The Viking formation ash beds may have been derived from the late phases of one of these intrusions.

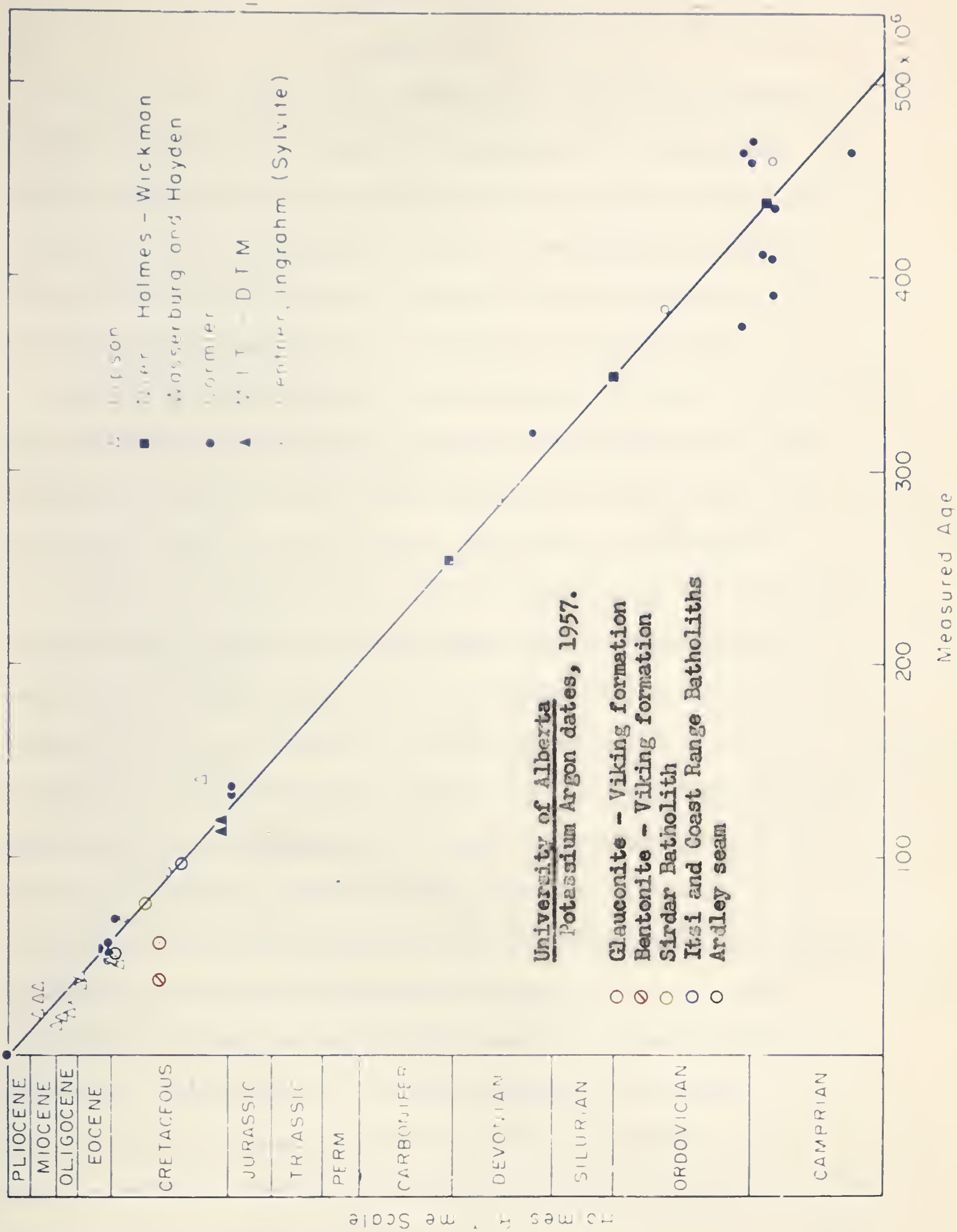
Holmes - Wickman
Wasserburg and Hayden
M I T - D T M
Ingrahm (Sylvite)
University of Alberta
Potassium Argon dates, 1957.
Glauconite - Viking formation
Bentonite - Viking formation
Sirdar Batholith
Itsi and Coast Range Batholiths
Ardley seam
100
200
300
400
500 x 10^6
Measured Age
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
CRETACEOUS
JURASSIC
PERM
ORDOVICIAN

Figure 12

CHAPTER SIX

PROVENANCE

The detrital heavy mineral assemblage of the Viking formation studied was derived from igneous, metamorphic, and sedimentary sources. However most of the detrital heavy minerals appear to be multi-cycle, with an immediate source in pre-existing sedimentary rocks. An increase in unstable minerals such as plagioclase and hornblende to the west suggests a source in that direction.

There are several possible source rocks in the west, all of which may have contributed some sediment to the Viking sea. The Blairmore formation in the foothills and Rocky Mountain areas is considered to have been one source. The chert in the Blairmore may be the source of the chert present in the Viking. The writer has not examined any heavy mineral suites from the Blairmore and there is no detailed account of the petrography of the Blairmore known to the writer. However the erosional surface at the top of the Blairmore and the absence of Viking and Joli Fou in the foothills and Rocky Mountains suggests that erosion took place during Viking time in these areas. Another possible source for the chert in the Viking formation is the Beaverfoot and Brisco (Ordovician and Silurian) formations in the Selkirk Mountains of British Columbia. These formations are thick-and thin-bedded limestones containing bands of dark chert. (Evans 1932). The quartz present in the Viking may be eroded Wonah quartzite which consists of quartzite and friable sandstone. The Wonah quartzite underlies the Brisco formation in the Selkirk Mountains.

The bentonitic ash beds in the Viking formation have been considered by most workers to be synchronous with the Crowsnest

Volcanics. However, a heavy mineral study of the Crowsnest Volcanics (Beveridge 1956) indicates a high concentration of sphene and little or no zircon. On examination of heavy mineral separates from a bentonitic ash bed in the Armena field, zircon was found to be fairly common and sphene rare or absent. In the light of this evidence the probability of the same extrusion source for both the Crowsnest Volcanics and the Viking bentonitic ash beds seems unlikely. The exact source of the bentonitic ash beds is very difficult to establish as most of the intrusions west in the Selkirks show no remnants of volcanism. Age determinations have been made for some of the major intrusions from the Nelson Batholith in southern British Columbia to the Itsi Batholith in the Yukon. The age determinations indicate a major period of intrusion approximately 100 million years ago with igneous intrusions occurring intermittently throughout the rest of Cretaceous time. The Sirdar Batholith near Cranbrook in British Columbia is one of the later intrusions and has been dated at 82 million years. If the Sirdar Batholith did have associated volcanic activity or similar minor intrusions in Central B.C. it may possibly have been the source of the bentonitic ash beds within the Viking formation.

The hyacinth variety of zircon present in the Viking formation is well rounded and, because hyacinth zircon is presumed to be Pre-Cambrian in age, probably represents a reworked constituent from pre-existing sediments. There are three known possible sources of Pre-Cambrian hyacinth zircons. (Beveridge, 1956). One source could be the Canadian Shield and would indicate a shield source for pre-existing sediments to the west. Another source could be the Creston quartzite

of Pre-Cambrian age which occurs in the general Kimberley area of southeastern British Columbia. The third known source is the Pre-Cambrian Purcell diorite sill, which also occurs in the Kimberley area.

The widespread occurrence of angular apatite, and the presence of angular plagioclase and amphibole in the western wells, may suggest that intrusives west of the Selkirk were unroofed and contributed sediment to the Viking sea. However, other fresh angular minerals associated with an igneous source are absent.

Considerable study will be required on the possible source rocks for the Viking formation before any definite statement can be made as to the source.

CONCLUSIONS

The Viking formation in Central Alberta is a marine deposit consisting essentially of sandstone, sandy shales and shales. Glauconitic zones, sideritic ironstone bands, and bentonitic ash beds occur at various positions throughout the Viking.

The Viking formation in the four wells used in this study are all the same age and correlate with the type area of Viking at Viking Kinsella. The above correlation was based on palaeontological and lithologic evidence. The absence of sporomorphs in the Norbuck 2-6 well has been interpreted to mean near-shore conditions and is a suggested approach to mapping the Viking shoreline.

The physical age of the Viking formation has been determined by potassium-argon dating methods and yields two values, 45 million years and 63 million years. The former age was determined on a bentonitic ash bed; the latter age was determined on a concentrated glauconite sample. These ages are believed to be low due to potassium adsorption and argon leakage; a suggested age being 80 million years with reference to Holmes B Time Scale.

The source of the Viking sediments is believed to be the Blairmore-Kootenay group to the west in the foothills and Rocky Mountain region. The bentonitic ash beds are believed to be derived from volcanoes associated with the late phases of Mid-Cretaceous intrusions of British Columbia.

Deposition of the Viking formation took place in a shallow marine embayment with a maximum depth in Central Alberta of 150 feet. The presence of glauconite and siderite suggest slightly reducing conditions and a slow rate of deposition.

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APPENDIX A

CORE DESCRIPTIONS

Imperial Norbuck #2 - 6
Lsd. 2, Sec. 6, Twp. 47, Rge. 4 W5M
K. R. 3014'
Viking Top at 5579'

Diamond Core #9 - 5566' to 5604' - Recovery 41'0"

5566 - 5581 SHALE, black to dark grey, micromicaceous conchoidal fracture, silty non calcareous, fine sandstone bleb at 5577, fish remains concentrated along certain bedding planes.

5581 - 5586 SHALE, black to dark grey micromicaceous silty conchoidal fracture fish scales present, with siltstone laminations and interbeds, 2 large interbeds at 5581 and 5583.5, $\frac{1}{4}$" x 1" respectively these show cross-bedded and cut and fill structure, one small sandstone bleb at 5585.5 $\frac{1}{2}$" thick composed of medium grained sandstone fragments, pyrite scattered throughout the siltstone and sandstone blebs. (See Pl. III, fig. 4; Pl. VI, fig. 7)

5586 - 5598 SHALE, black to dark grey micromicaceous silty conchoidal fracture non calcareous, fish scales and remains with interbeds of cross-bedded siltstone in beds up to 2" thick, also interbeds of cross-bedded sandstone, fine to medium grained in beds up to 2" thick, increase in number of sand and silt interbeds toward base, cut and fill structure associated with the sandstone and siltstone some scattered chert pebbles with pyrite closely associated with them, minor slickensides present in the shale. (See Pl. II, fig. 4)

5598 - 5598.2 CONGLOMERATE, dark grey to grey composed of rounded to sub angular chert pebbles up to $\frac{1}{4}$" in diameter, pink color present in some grains, set in a medium grained sand matrix, pyrite replacement of some pebbles, silty and argillaceous, plant remains appear to be present. (See Pl. VII, fig. 2)

5598.2 - 5599.6 SHALE, black non calcareous micromicaceous conchoidal fracture, silty, fish remains.

5599.6 - 5600 SANDSTONE, grey, fine to medium grained non calcareous, silty, interbedded with SHALE (20%) black micromicaceous, in fine lamination showing evidence of reworking, pyrobitumen and worm burrows present.

5600 - 5600.2 CONGLOMERATE, grey to dark grey composed of rounded to sub angular chert pebbles up to $\frac{1}{2}$" in size, few pebbles are, fractures set in a matrix (50%) consisting of sandstone grey, medium grained non calcareous silty, argillaceous. (See Pl. I, fig. 2; Pl. VII, fig. 1)

5600.2 - 5606 SANDSTONE, (70%) grey to dark grey, medium to fine grained, non calcareous, salt and pepper, glauconitic with amount of glauconite increasing toward base silty, worm and animal burrows throughout, evidence of intense reworking resulting in a mixing of shale and sandstone SHALE (30%) black micromicaceous, non calcareous small blebs of pyrite, vertical fractures, carbonaceous material. (See Pl. IV, fig. 3; Pl. VI, fig. 12)

Diamond Core #10 - 5606' to 5646' - Recovery 40'0"

5606 - 5611 SANDSTONE, as above. (See Pl. IV, fig. 2; Pl. VI, fig. 11)

5611 - 5614 SANDSTONE, (90%) grey to light grey, salt and pepper, fine to medium grained, non calcareous glauconitic, silty, with laminations (up to ½") of SHALE black, micromicaceous, siderite nodules at 5611 (up to 1" thick) pyrobitumen or carbonaceous material present in shale and associated with the siderite.

5614 - 5632 SANDSTONE, (60%) grey to dark grey fine to medium grained non calcareous, salt and pepper, silty, glauconitic, worm burrows, mixing of shale and sandstone indicating reworking shale and siltstone (40%) black to grey non calcareous carbonaceous occurring as thin laminations throughout sandstone with increasing shaly content toward base. (See Pl. V, fig. 3)

5632 - 5641 SHALE, black micromicaceous calcareous, carbonaceous material and fish remains, some stringers and blebs of silt and sandstone. (See Pl. VI, fig. 10)

5641 - 5646 SHALE, black micromicaceous non calcareous silty carbonaceous material with intercalated siltstone and sandstone grey salt and pepper, non calcareous fine grained, numerous worm burrows evidence of reworking shown by intermixing of shale and sandstone.

5646 - 5649 not cored or tally correction.

Diamond Core #11 - 5649' to 5698' - Recovery 49'0"

5649 - 5665 SHALE, black micromicaceous non calcareous, silty conchoidal fracture with quite apparent vertical fracture with recrystallized calcite at 5659, carbonaceous material present stringers and blebs of silt and sand present throughout, minor amounts of scattered pyrite.

5665 - 5665.2 BENTONITE ash bed with shale as above.

5665.2 - 5666 SHALE, as above.

5666 - 5666.1 BENTONITE and SHALE as above.

5666.1 - 5674 SHALE, as above with fish scales being present.

5674 - 5674.1 BENTONITE and SHALE as above.

5674.1 - 5690 SHALE, as above with Brachiopod.

5690 - 5690.1 BENTONITE and shale as above.

5690.1 - 5698 SHALE, as above.

Imperial Joffre #2-21
Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M
K.B. 2852
Viking Top at 4728

Diamond Core #1 - 4720' to 4751' - Recovery 31'0"

4720 - 4728 SHALE, black to grey, micromicaceous, conchoidal fracture, poker chip type shale, non calcareous, fish scales present, silty with several siltstone bands $\frac{1}{2}$" to 1" in thickness, pyrobituman (in amounts below $\frac{1}{4}$ cm) associated with the siltstone.

4728 - 4728.4 GRIT, grey to black, pebbles $\frac{1}{4}$" thick set in a shaly matric (60% matrix) main grit constituents are chert pebbles and quartz grains. This marker is considered to be the top of the Viking member. (See Pl. II, fig. 3)

4728.4 - 4728.5 SHALE, black to grey, poker chip type, micromicaceous, non calcareous, silty, small coarse grained sandstone lamina $\frac{1}{4}$" to $\frac{1}{2}$" thick, not of uniform thickness, present in the middle of the shale band.

4728.5 - 4729.1 SANDSTONE, light grey, salt and pepper, coarse to very coarse grained, subangular, poorly sorted, mainly chert and quartz grains set in an authigenic crystalline calcite matrix cross-bedded (45%), no noticeable graded bedding. (See Pl. VII, fig. 3)

4729.1 - 4730 SHALE, black to grey, fish scales present, non calcareous, with interbedded SANDSTONE grey-brown lensy some porosity and oil staining. Minor cut and fill structure.

4730 - 4730.2 SANDSTONE, grey to brown, salt and pepper, non calcareous, some scattered chert pebbles, poor effective porosity oil stained.

4730.2 - 4731 SHALE, dark grey non calcareous, micromicaceous, some scattered chert and quartz pebbles (up to ¼") silty, with sandstone stringers in cut and fill structure.

4731 - 4731.8 CONGLOMERATE, dark to medium grey, composed of rounded to sub-angular chert pebbles up to ½", slightly larger at base, sandy matrix with calcareous cement and some argillaceous material. (See Pl. 1, fig. 1)

4731.8 - 4738 SILTSTONE,(60%) grey to brown, showing cut and fill structure, interbedded with SHALE (40%) dark grey non calcareous micromicaceous.

4738 - 4743 SILTSTONE, grey non calcareous, argillaceous, some light speckled sandstone stringers and blebs.

4743 - 4749 SILTSTONE, grey non calcareous, slightly glauconitic, argillaceous with shale content increasing toward basal part, worm burrows present in top foot, ½" in diameter and sand filled. (See Pl. IV, fig. 4)

4749 - 4751 SANDSTONE, grey, fine grained, salt and pepper, argillaceous, increase in grain size at base to fine conglomerate, some beds up to 2" thick show graded bedding, some porosity, sand filled worm burrows present. (See Pl. 1, fig. 3)

Diamond Core #2 - 4751' to 4788' - Recovery 38'0"

4751 - 4753.3 SANDSTONE, grey, medium grained, salt and pepper, trace glauconite slightly calcareous, shaly with shale content increasing toward base shale dark grey to black, poker chip type, micromicaceous silty.

4753.3 - 4755.5 SHALE, dark grey to black, non calcareous, micromicaceous, poker chip type, trace glauconite, small sandstone stringer up to ½" present throughout shale, many fish scales.

4755.5 - 4755.6 SANDSTONE, grey to dark grey, coarse-grained, salt and pepper, slightly calcareous, graded bedding with conglomerate at base, good porosity and permeability.

4755.6 - 4759.6 SANDSTONE, grey to dark grey, coarse grained, composed of rounded to sub-angular, light and dark, chert pebbles, slightly argillaceous and slightly glauconitic, good porosity and permeability. (See Pl. II, fig. 1)

4759.6 - 4764.6 SANDSTONE, grey, salt and pepper coarse grained grading to medium and fine sandstone toward base, glauconitic with the glauconite intimately associated with dark brown siderite in bands up to 1" thick, shaly with shale partings up to ¼" thick, spores,gastropods and pyrobitumen are found in the shale partings. Sandstone also becoming quite silty at base.

4764.6 - 4769.6 SILTSTONE, dark grey to grey, non calcareous glauconitic, stringer and blebs of coarse siltstone, siltstone getting finer toward base and grading to shale. (See Pl. V, fig. 2)

4769.6 - 4788 SHALE, dark grey to black, non calcareous, silty, micromicaceous, fish scales present.

Imperial Armena #6-11
Lsd. 6, Sec. 11, Twp. 48, Rge. 21 W4M
K.B. 2482'
Viking Top at 3272

Diamond Core #1 - 3280' to 3315' - Recovery 20'3"

3280 - 3282.7 SHALE, black, non calcareous, carbonaceous, silty, micromicaceous fish scales, scattered throughout are blebs and lenses of cross bedded sandstone up to 2" thick exhibiting cut and fill and slumping type structures. (See Pl. III, figs. 1 and 2; Pl. VI, fig. 3)

3282.7 - 3284 SHALE, black non calcareous, carbonaceous, silty, micromicaceous, with sandstone stringers.

3284 - 3293 SHALE, black non calcareous, carbonaceous, some microscopic pyrite material fish scales and bones present, scattered pyrobituminous material, silty, with blebs and lenses of sandstone and siltstone showing cut and fill and slumping structures. (See Pl. III, fig. 3)

3293 - 3298 SHALE, as above, with interbedded SANDSTONE (30%) grey salt and pepper, in bed 4" thick, showing cross-bedding and cut and fill, and slumping structures. (See Pl. I, fig. 4; Pl. VII, fig. 5 and 6)

3298 - 3304 SANDSTONE, grey, salt and pepper, medium to coarse grained, cross-bedded non calcareous, silty, decreasing slightly in grain size toward base, porous sideritic bands up to 1" thick, shaly with shale bands up to ½" thick. Shale carbonaceous and micromicaceous. (See Pl. V, fig. 1; Pl. VI, fig. 2; Pl. VII, figs. 4,7,8,9)

3304 - 3308 SANDSTONE, grey, salt and pepper, fine to medium grained grading to fine at base, glauconite concentrations in thin bands throughout, minor cross-bedding silty, slightly porous, with thin interbeds of shale black carbonaceous micromicaceous, poorly preserved gastropod. (See Pl. VI, figs. 1,4,5,6,9)

3308 - 3308.5 BENTONITE, grey fissile, volcanic ash fall?

3308 - 3315 SANDSTONE, grey, salt and pepper, fine-medium grained minor cross-bedding, silty, slight porosity with stringers and blebs of SHALE black micromicaceous, worm burrows, amount of shale increasing toward base. (See Pl. II, fig. 2)

Diamond Core #2 - 3315' to 3350' - Recovery 33'8"

3315 - 3320 SANDSTONE, as above. (See Pl. V, fig. 4)

3320 - 3338 SILTSTONE, (60%) dark grey to black carbonaceous, with sandstone blebs, worm burrows, intercalated with SHALE (40%) black micromicaceous sand and silt blebs, non calcareous, fish scales, shale content increasing toward base. (See Pl. IV, fig. 1; Pl. VI, fig. 8)

3338 - 3346 SANDSTONE, grey to dark grey, salt and pepper, slump structure, with SHALE (20%) micromicaceous non calcareous dark grey to black, fish scales, worm burrows in small partings and bands increasing toward base of core. (See Pl. VII, figs. 11, 12)

3346 - 3348 SHALE, black micromicaceous, carbonaceous, slump structure, some fissility at base, noncalcareous, worm burrows, fine siltstone laminations throughout.

3348 - 3350 SANDSTONE, grey, salt and pepper, fine grained, carbonaceous, shaly partings, noncalcareous, slump structure, worm burrows. (See Pl. VII, fig. 10)

Superior Joseph Lake #11
Lsd. 12, Sec. 13, Twp 50, Rge 22 W 4 M
K.B. 2557'
Viking Top at 3220'

Core #1 - 3229' to 3231' - Recovery 10"

3229 - 3231 SHALE, grey to dark grey, micromicaceous, conchoidal fracture, with fish scales, grading to silty shale towards the base.

Core #2 - 3231' to 3235' - Recovery 4'

3231 - 3233 SHALE, as above, silty in top 4", a 1" bentonite band 8 inches from the top.

3233 - 3234.5 SANDSTONE, grey, fine grained, salt and pepper, subangular grains, shaly matrix, micaceous tight, unstained, slightly calcareous.

3234.5 - 3235 SILTSTONE, grey, noncalcareous, shaly micaceous.

Core #3 - 3235' to 3242' - Recovery 7'

3235 - 3235.5 SANDSTONE AND SILTSTONE, as above.

3235.5 - 3239 SILTSTONE AND SHALE, interbedded with sandstone laminae and bands up to 1 inch increasing towards the base.

3239 - 3242 SILTSTONE AND SHALE, interbedded as above, with small sandstone laminae.

Core #4 - 3242' to 3252' - Recovery 10'

3242 - 3252 SILTSTONE AND SHALE, as above.

Core #5 - 3252' to 3256.5' - Recovery 4'6"

3252 - 3254 SILTSTONE AND SHALE, as above.

3254 - 3256.5 SHALE, as above with sandstone bands up to 1 inch thick; sandstone, grey, coarse grained, salt and pepper, non calcareous, micaceous.

Core #6 - 3256.5' to 3260' - Recovery 1'4"

3256.5 - 3257 SANDSTONE, grey, medium grained, salt and pepper, grains subangular, shaly matrix, micaceous.

3257 - 3260 SHALE AND SANDSTONE, interbedded, as above.

Core #7 - 3260' to 3260.5' - Recovery 6"

3260 - 3260.5 SANDSTONE, grey, medium grained, salt and pepper, grains subangular, porous, non calcareous, drilling mud intermixed with sandstone.

Core #8 - 3260.5' to 3261' - Recovery 6"

3260.5 - 3261 SANDSTONE, as above.

Core #9 - 3261' to 3261.2' - Recovery 2"

3261 - 3261.2 as above.

Core #10, 11, 12 - 3261.2' to 3262' - Recovery 10"

3261.2 - 3262 SANDSTONE, as above, but poorly shown as drilling mud is obscuring sand.

Core #13 - 3262' to 3262.5' - Recovery 6"

3262 - 3262.5 SANDSTONE, grey, coarse grained, salt and pepper, some pyrobitumen present.

Core #14 - 3262.5' to 3263' - Recovery 6"

3262.5 - 3263 As above.

Core #15 - 3263' to 3263.5' - Recovery 6"

3263 - 3263.5 SANDSTONE, as above, badly crumpled.

Core #16 - 3263.5' - 3264' - Recovery 6"

3263.5 - 3264 SANDSTONE, as above with shaly matrix and light grey siltstone interbedded.

Core #17 - 3264' to 3264.7' - Recovery 8"

3264 - 3264.7 As above.

Core #18 - 3264.7' to 3265' - Recovery 4"

3264.7 - 3265 As Above.

Core #19 - 3265' to 3265.5' - Recovery 6"

3265 - 3265.5 As above.

Core #20 - 3265.5' to 3268.5'- Recovery 3'

3265.5 - 3268.5 SANDSTONE, grey, medium grained, salt and pepper, grains subangular, porous slightly calcareous, glauconitic, clean becoming finer towards base and shale interbedded.

Core #21 - 3268.5' to 3269' - Recovery 6"

3268.5 - 3269 As above.

Drilled Interval - 3269' to 3274'.

Core #22 - 3274' to 3274.5' - Recovery 6"

3274 - 3274.5 SANDSTONE, as above, medium grained, argillaceous, with thin shale laminations throughout.

Core #23 - 3274.5' to 3279.8' - Recovery 5'4".

3274.5 - 3279.8 As above.

Core #24 - 3279.8' to 3280.2' - Recovery 5".

3279.8 - 3280.2 SANDSTONE, grey, medium grained, salt and pepper, clean.

Core #25 - 3280.2' to 3285' - Recovery 4'8".

3280.2 - 3285 SANDSTONE, grey, medium grained salt and pepper, with shaly laminations and one 1 inch shale band.

Imperial Kinsella #25
Lsd. 10, Sec. 10, Twp. 48, Rge. 12 W4M
K.B. 2341'
Viking Top at 2147' after S.R.L. Harding

Core #1 - 2132' to 2146' - Recovery 14'

2132 - 2132.7 SHALE, dark grey, fissile.

2132.7 - 2133 CLAY IRONSTONE

2133 - 2142.5 SHALE, dark grey, fissile; few thin sand patches in lower most 7 feet.

2142.5 - 2142.8 CLAY IRONSTONE

2142.8 - 2144.6 SHALE, dark grey, fissile.

2144.6 - 2144.9 SANDSTONE, light grey medium to coarse grained, irregularily interbedded with dark grey arenaceous shale.

2144.9 - 2146 SHALE, dark grey, arenaceous compact, with few fish scales.

Core #2 - 2146 to 2161 - Recovery 15'.

2146 - 2146.5 SHALE, dark grey, with small patches of coarse grey sand (up to ¼" diameter).

2146.5 - 2147 SANDSTONE AND SHALE, about 50% of each, irregularity interbedded. Sandstone, coarse grained, light grey with numerous small angular black chert pebbles.

2147 - 2149 SHALE, dark grey, fissile, with few thin layers of silt.

2149 - 2149.1 SANDSTONE, grey, medium grained with interbedded shale.

2149.1 - 2149.2 SILTSTONE AND SHALE, crossbedded and lensing.

2149.2 - 2153.1 SHALE, dark grey, somewhat bentonitic, with few stringers of silt up to ¼ inch thick.

2153.1 - 2153.4 SILT AND SHALE, interbedded in equal amounts.

2153.4 - 2155.9 SHALE, dark grey, with small nodular masses of medium grained sand and few thin silt layers.

2155.9 - 2156 BENTONITE, pale greenish-grey.

2156 - 2156.5 SANDSTONE, grey, medium grained, interbedded with little dark grey shale, with small black chert pebbles.

2156.5 - 2157 IRONSTONE.

2157 - 2157.5 SHALE, dark grey, compact, thick bedded, arenaceous.

2157.5 - 2161 SHALE, dark grey, thin bedded and fissile, with few sand and silt galls.

Core #3 - 2161' to 2170' - Recovery 9'.

2161 - 2166 SHALE, dark grey, similar to above.

2166 - 2169 SANDSTONE, grey, medium grained, compact, with little interbedded shale. Lightly oil stained in parts numerous small black chert pebbles throughout.

2169 - 2169.8 SHALE, dark grey, with numerous small modular masses of sand, giving core a mottled appearance.

2169.8 - 2170 SANDSTONE, medium grained.

Core #4 - 2170' to 2188' - Recovery 15'

2170 - 2171 SANDSTONE, light grey, fine grained, very hard and compact, well cemented.

2171 - 2172 SANDSTONE, medium to fine grained porous, with slight petroliferous odor and some oil bleeding.

2172 - 2178.5 SANDSTONE, similar to above, fine grained material approaching siltstone.

2178.5 - 2182 SHALE, with discontinuous sand lenses throughout. Some shale content.

2182 - 2184.5 SANDSTONE, medium grained, mainly compact but friable in parts; weak petroliferous odor. Many small black chert pebbles.

2184.5 - 2188 SANDSTONE, similar to above but more compact and more shale content.

Core #5 - 2188' to 2205' - Recovery 12'

2188 - 2191 SANDSTONE AND SHALE, sandstone fine grained, lensing; Shale, arenaceous, compact, with nodular patches of sand and silt.

2191 - 2198 SHALE, dark grey, fissile, with silt and sand galls.

2198 - 2205 SHALE, dark grey, thin bedded and very fissile, with few bands of hard arenaceous shale containing little sand.

Core #6 - 2205' to 2215' - Recovery 10'

2205 - 2215 SHALE, dark grey, thin bedded and fissile, with little silt in upper part.

APPENDIX B

THIN SECTION DESCRIPTIONS

Imperial Norbuck 2-6
Lsd. 2, Sec. 6, Twp. 47, Rge. 4 W5M

57-F78 - Depth 5584 Feet (Pl. VI, fig. 7)

Megascopic description

SANDSTONE, medium grey, very fine grained, slightly calcareous, medium sorting, shows good crossbedding, thin argillaceous partings.

Microscopic description

TEXTURE: Very fine grained sandstone, subangular to subrounded, very slight or no porosity, cementation is silica overgrowths, medium sorting, clastic.
STRUCTURE: Small-scale cross-bedding.
MINERALOGY: Quartz 60%, Siliceous rock fragments 10% - mainly argillite fragments and some chert fragments, twinned plagioclase less than 1%, Matrix 25% - composed of fine silt and illitic clay material.
CEMENT: Total cement 5% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Grey because of the argillaceous matrix and rock fragments.
CLASSIFICATION: Lithic sandstone.

57-F80 - Depth 5592 Feet.

Megascopic description

SANDSTONE, medium grey, very fine grained, salt and pepper, noncalcareous, slightly glauconitic, very poor porosity, medium sorting, cross-bedded with shaly partings and one medium grained sandstone lamination, argillaceous concentrations give light and dark alternating laminations.

Microscopic description

TEXTURE: Very fine grained sandstone, subangular to subrounded, porosity less than 1%, cementation slight - as quartz overgrowth, medium to poor sorting, an argillaceous matrix binds grains, clastic.
STRUCTURE: Argillaceous concentrations parallel to bedding.
MINERALOGY: Quartz 50%, Siliceous rock fragments 15% - mainly argillite grains and some chert grains, Glauconite less than 1%, Matrix 30% - composed of fine silt size quartz and illitic clay material.

CEMENT: Total cement 4% as silica overgrowth on quartz.
SIGNIFICANCE OF COLOUR: Grey because of the argillaceous matrix and rock fragments.
CLASSIFICATION: Lithic sandstone.

57-F83 - Depth 5598 Feet (Pl. VII, fig. 2)

Megascopic description

CONGLOMERATE, grey matrix with black and light grey chert pebbles, pebble size, overlain by fissile black shale, poor sorting, noncalcareous, pyrite has replaced some of the pebbles, no porosity, cut and fill structure seen at contact of underlying shale, the conglomerate bed in only $1\frac{1}{2}$ inches thick.

Microscopic description

TEXTURE: Very fine pebble grain size, pebbles rounded, smaller grains subangular to subrounded, no porosity, cementation silica overgrowths poor sorting, clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 70% composed of chert, argillite, and quartzite fragments, Quartz 25%, Twinned plagioclase 3 to 45%, Pyrite 1% - disseminated in large argillite fragments.
CEMENT: Total cement 2% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Grey to black because of the presence of rock fragments.
REMARKS: Some of the rock fragments have weathered outer shells some being light and others dark to black.
CLASSIFICATION: Lithic pebble conglomerate.

57-F85 - Depth 5599.6 Feet

Megascopic description

SANDSTONE, light grey with black argillaceous stringers throughout, fine grained, salt and pepper, noncalcareous, no porosity, worm burrows and reworked, a few argillaceous stringers and bits of pyrobitumen, pyrite replacing some grains.

Microscopic description

TEXTURE: Fine grained sandstone, angular to subangular, tight packing, no porosity, cementation silica overgrowths on quartz, poor sorting, clastic.
STRUCTURE: None observed.
MINERALOGY: Quartz 55%, Siliceous rock fragments 25% - composed of chert, argillite and some quartzite fragments, Twinned plagioclase 5% - plagioclase has been sericitized in part, other grains are quite fresh and angular, Pyrite 2% - dissemenated but mainly replacing argillite fragments sometimes completely, Matrix 10% - composed of fine silt and illitic clay material.

CEMENT: Total cement 5% as silica overgrowth on quartz.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments and matrix.
CLASSIFICATION: Lithic sandstone.

57-F87 - Depth 5600 Feet (Pl. VII, fig. 1)

Megascopic description

CONGLOMERATE, mainly dark grey with some light grey to white pebbles in a grey matrix, bimodal medium pebble size, poor sorting, salt and pepper, noncalcareous, pyritic, no porosity, two inch conglomerate bed overlies and is overlain by shale, pyrite replacing fragments and as fracture infillings.

Microscopic description

TEXTURE: Fine pebble conglomerate grain size, pebbles rounded, smaller grains subangular to subrounded, tight packing, no porosity, cementation slight as silica overgrowths, poor sorting, clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 60% - mainly chert and argillite, Quartz 20%, Twinned feldspar 4% - some of the feldspar is sericitized - the rest being fresh and angular, Pyrite 4% - replacing argillite fragments and some disseminated, Matrix 10% - argillaceous material (illitic).
CEMENT: Total cement 2% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Grey because of the rock fragments and matrix.
REMARKS: Some of the pebbles have been fractured and infilled prior to deposition, some of the cherts have organic material within them.
CLASSIFICATION: Lithic pebble conglomerate.

57-F88 - Depth 5604 Feet (Pl. VI, fig. 12)

Megascopic description

SANDSTONE, light grey with black argillaceous laminae throughout, very fine grained, salt and pepper, medium sorting, glauconitic, pyritic, no porosity, reworked type sediment, worm burrows.

Microscopic description

TEXTURE: Very fine grained sandstone, angular to subangular, tight packing, porosity less than 1%, cementation silica, poor sorting, clastic.
STRUCTURE: Argillaceous bands approximately parallel to bedding and an abrupt change in grain size in one 4 mm. band, scour and fill structure, lense shaped forms infilled by quartz and rock fragments and surrounded by argillaceous laminae.

MINERALOGY: Quartz 50%, Siliceous rock fragments 25% - composed of chert, argillite, quartzite, and siliceous volcanics, Pyrite 4% - disseminated throughout with some local concentration, Glauconite 1%, Twinned plagioclase less than 1%, Collophane less than 1%, Calcite less than 1%, Matrix 20% - composed mainly of illitic clay and fine silt.
CEMENT: Total Cement 2% - $1\frac{1}{2}$% silica overgrowths, $\frac{1}{2}$% calcite.
SIGNIFICANCE OF COLOUR: Dark color because of rock fragments, matrix and pyrite, light areas show concentration of quartz.
REMARKS: The matrix has a reddish brown colour possibly because of the presence of iron, there is a tendency for more pyrite to be in the matrix than scattered evenly throughout.

57-F89 - Depth 5608 Feet (Pl. VI, fig. 11)

Megascopic description

SANDSTONE, grey with black stringers of shale, fine grained, salt and pepper, glauconitic, noncalcareous, no porosity, poor sorting, glauconite concentrated along one parting, animal burrows, scour and fill, reworked.

Microscopic description

TEXTURE: Fine grained sandstone, subrounded to subangular, tight packing, no porosity, cementation silica overgrowths on quartz, poor sorting, clastic.
STRUCTURE: Alternation of grain size parallel to bedding.
MINERALOGY: Quartz 65%, Siliceous rock fragments 20% - mainly argillite and chert, Pyrite 2% - disseminated and is some areas appears to be detrital grains, Glauconite 1%, Twinned feldspar less than 1% - some of the feldspar is sericitized, Matrix 10% - composed of illitic clay material and fine silt - concentrated in some areas.
CEMENT: Total cement 7% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Dark due to presence of rock fragments and matrix.
CLASSIFICATION: Lithic sandstone.

57-F97 - Depth 5610.8 Feet

Megascopic description

SANDSTONE, medium grey, fine grained with ironstone (siderite) bands throughout, salt and pepper, glauconitic, noncalcareous, slightly porous, medium to good sorting, small pieces of drift wood throughout, some of the siderite is in nodules others in bands, there are a few shaly partings.

Microscopic description

TEXTURE: Fine grained sandstone, subangular to subrounded, tight packing, porosity less than 1%, cementation-silica overgrowths, medium sorting, has some siderite (clastic in appearance) bands with scattered quartz and rock fragments throughout, clastic.
STRUCTURE: Siderite bands roughly parallel to bedding.
MINERALOGY: Quartz 65%, Siliceous rock fragments 30% - mainly chert and argillite with some siliceous volcanics and quartzite, Siderite 2% - in bands at top and bottom about 60%, Glauconite 1%, Twinned plagioclase less than 1%, Collophane less than 1%.
CEMENT: Total cement 5% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments.
REMARKS: The quartz grains in places almost make a mosaic - caused by overgrowth of silica.
CLASSIFICATION: Lithic sandstone.

57-F105 - Depth 5618 Feet

Megascopic description

SANDSTONE, light grey, very fine grained, salt and pepper, slightly glauconitic, noncalcareous, well sorted, no porosity, worn burrows and reworked type sediment.

Microscopic description

TEXTURE: Very fine grained sandstone, subangular to subrounded, tight packing, porosity less than 1%, cementation silica and calcite, well sorted, clastic.
STRUCTURE: Light and dark zones approximately parallel to bedding.
MINERALOGY: Quartz 55%, Siliceous rock fragments 35% - composed of chert, argillite, quartzite, and siliceous volcanics, Pyrite 8% - concentrated along some bedding planes, Calcite 1%, Twinned plagioclase less than 1%, Glauconite less than 1%, Zircon less than 1%.
CEMENT: Total cement 6% - silica overgrowths 5%, calcite 1%.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments.
CLASSIFICATION: Lithic sandstone.

57-F107 - Depth 5633 Feet (Pl. VI, fig. 10)

Megascopic description

Ironstone, brown, very fine silt size, small circular patches $\frac{1}{4}$ mm. in diameter with coarser siderite and concentration of quartz, noncalcareous, slightly glauconitic, quartz is coarse silt size scattered throughout ironstone.

Microscopic description

TEXTURE: Very fine grained silt, rounding on quartz grains is angular to subrounded-siderite is subangular, tight packing, no cementation, well sorted with a few coarse silt size quartz grains throughout, clastic.
STRUCTURE: Small circular infilled borings (½mm. to 2 mm.) quartz grains concentrated in these areas (animal borings).
MINERALOGY: Siderite 80%, Quartz 10%, Siliceous rock fragments 5% - mainly chert with some argillite fragments and a few quartzite fragments, black opaques 2% - may be decayed organic material - phosphatic, calcite less than 1%.
CEMENT: None.
SIGNIFICANCE OF COLOUR: Brown due to presence of siderite.
REMARKS: The siderite concentrated in the borings is coarser grained than that in the overall section.
CLASSIFICATION: Siderite ironstone.

57-F111 - Depth 5645 Feet

Megascopic description

SANDSTONE, medium grey to dark grey, very fine grained, salt and pepper, noncalcareous, glauconitic, medium sorting, very slight porosity, shaly partings at top with white mica along partings, fine sandstone laminae.

Microscopic description

TEXTURE: Very fine grained sandstone, subrounded to angular, tight packing, porosity less than 1%, silica overgrowth cementation, medium sorting, clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 50% - mainly chert and argillite with some quartzite and siliceous volcanic fragments, Quartz 25%, Siderite 20%, Opaques 2%, Twinned plagioclase less than 1%, Glauconite less than 1%.
CEMENT: Total cement 1% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Dark due to rock fragments - brownish due to siderite.
REMARKS: Quartz, siderite, and rock fragments are all approximately the same size.
CLASSIFICATION: Lithic sandstone.

Imperial Armens 6-11V
Lsd. 6, Sec. 11, Twp. 48, Rge. 21 W4M

57-F18 - Depth 3281.3 Feet to 3281.6 Feet. (Pl. VI, fig. 3)

Megascopic description

SILTSTONE, dark grey and light grey intermixed, medium grained, medium to poor sorting, cross-bedded, animal burrows, reworked, minor scour and fill, an argillaceous matrix acts as a cement.

Microscopic description

TEXTURE: Medium grained silt, subrounded to subangular quartz grains, porosity less than 1%, medium sorting, matrix of illitic clay and very fine filt, a coarse silt overlies the medium silt.
STRUCTURE: Very thin alternating light and dark laminae, slump structure, scour and fill, an abrupt change from medium silt to coarse silt at the top.
MINERALOGY: Quartz 40%, Siliceous rock fragments 8% - mainly chert and argillite fragments, Black opaques 8%, Glauconite less than 1%, Twinned plagioclase less than 1%, Tourmaline less than 1%, Calcite less than 1%, Pyrite less than 1%, Matrix 40% - fine silt and illitic clay.
CEMENT: Total cement 3% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Dark areas matrix, light areas more abundant quartz.
CLASSIFICATION: Lithic siltstone.

57-F20 - Depth 3291.4 Feet to 3291.5 Feet

Megascopic description

SANDSTONE, dark grey, coarse grained, salt and pepper, well sorted, siliceous cement, overlain by SHALE, black, noncalcareous, silty, fissile micaceous, sandstone grains appear to have the long axes parallel to bedding, sharp contact between shale and sandstone.

Microscopic description

TEXTURE: Very coarse grained sandstone, subrounded to rounded, normal packing, porosity less than 1%, cementation (none), matrix of clay, silt and carbonaceous material, medium sorting, Clastic.
STRUCTURE: Long axes of grains are parallel to bedding, color banding in the shale parallel to bedding.
MINERALOGY: Siliceous rock fragments 70% - composed of chert, argillite, quartzite, and siliceous volcanies, Quartz 5% - most of the quartz grains are strained and may be caused by load metamorphism, Zircon less than 1% - as inclusions in quartz, Matrix 20% - siliceous, illitic and carbonaceous material.

CEMENT: None observed.
SIGNIFICANCE OF COLOUR: Gray because of the presence of rock fragments and matrix.
REMARKS: Some of the chert and rock fragments area weathered or leaching giving dark or light outer rims, some of the grains have pre-depositional fracture fillings.
CLASSIFICATION: Lithic sandstone.

57-F22 - Depth 3293.4 Feet to 3293.7 Feet (Pl. VII, fig. 6)

Megascopic description

SANDSTONE, dark and medium grey interbedded, medium grained, salt and pepper, well sorted, noncalcareous, siliceous cement, porous, cross-bedded.

Microscopic description

TEXTURE: Medium grained sandstone, subrounded to rounded, tight packing, porosity 8%, cementation silica overgrowths, well sorted, Clastic.
STRUCTURE: Light and dark bands $\frac{1}{2}$ mm. to 1 mm. thick.
MINERALOGY: Siliceous rock fragments 45% - composed of chert, argillite, and some quartzite and siliceous volcanics, Quartz 40%, Collophane 2%, Matrix 10% - fine silt and illitic clay material.
CEMENT: Total cement 5% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Light bands greater abundance of quartz, dark bands greater abundance of rock fragments.
REMARKS: Some of the rock fragments were fractured and infilled prior to deposition. Some of the quartz is euhedral as a result of overgrowths.
CLASSIFICATION: Lithic sandstone.

57-F23 - Depth 3295.5 Feet to 3295.7 Feet. (Pl. VII, fig. 5)

Megascopic description

SANDSTONE, grey, coarse grained, slight porosity, slightly calcareous, salt and pepper, medium to well sorted, a greenish grey matrix, grains vary in colour from light grey to black.

Microscopic description

TEXTURE: Very coarse grained sandstone, subrounded to rounded, porosity less than 1%, no cement, argillaeeous matrix, well sorted (sand grains), Clastic.
STRUCTURE: None observed.
MINERALOGY: Silicious rock fragments 35% - mainly chert and argillite, quartzite and siliceous volcanics, Quartz 10%, Plagioclase less than 1%, Matrix 50% - illitic clay, fine silt and carbonaceous material.
CEMENT: None observed.

SIGNIFICANCE OF COLOUR: Grey because of the presence of rock fragments and matrix.
REMARKS: Some rock fragments have been fractured and infilled by quartz pre-depositional, rock fragments are more angular than quartz, grains, some of the argillite and chert grains have been leached or weathered as they have light or dark outer rims, some of the chert bears organic relics.
CLASSIFICATION: Lithic sandstone.

57-F24 - Depth 3298.9 Feet to 3299.1 Feet (Pl. VII, Figs. 4, 9.)

Magascopic description

SANDSTONE, dark grey, very coarse grained, salt and pepper, slightly glauconitic, slightly calcareous, siliceous cement, bimodal, well sorted.

Microscopic description

TEXTURE, Very coarse grained sandstone, rock fragments subrounded to rounded, tight packing, porosity 8%, cementation selica and calcite, medium sorting (Bimodal), Clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 55% - mainly chert and argillite with some quartzite and siliceous volcanics, Quartz 40%, Alkaline feldspar 2%, Calcite 2%, Twinned plagioclase less than 1%, Muscovite less than 1%.
CEMENT: Total cement 5% - silica 3% as overgrowths on quartz and calcite 2%.
SIGNIFICANCE OF COLOUR: Grey due to the presence of rock fragments.
REMARKS: Some of the quartz grains are euhedral caused by authigenic overgrowth, some chert and argillite grains are weathered or leached as they have light and dark outer rims, the sandstone grains present represent a bimodal distribution with one range in the very course sandstone class and the other in the medium sandstone class, the quartz is in places tightly intergrown.
CLASSIFICATION: Lithic sandstone.

57-F26 - Depth 3300.6 Feet to 3301 Feet (pl. VI, fig. 2; Pl. VII, fig. 8)

Magascopic description

SANDSTONE, grey, medium grained, salt and pepper, glauconitic, slightly calcareous, siliceous cement, porous, well sorted.

Microscopic description

TEXTURE; Medium grained sandstone, subangular to subrounded, normal packing, porosity 20%, cementation silica and calcite, well sorted, Clastic.
STRUCTURE: A small structure of rhomb shaped carbonate 6 mm. long and $\frac{1}{2}$ mm. wide.

MINERALOGY: Quartz 55%, Siliceous rock fragments 40 - composed of chert, argillite, quartzite, and siliceous volcanies, Calcite 3%, Glauconite 2%, Muscovite less than 1%, Zircon less than 1%.
CEMENT: Total cement 8% - silica 5% as overgrowths on quartz and calcite 3% authigenic.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments.
REMARKS: Some quartz grains euhedral due to overgrowths, quartz grains are strained, some chert grains have organic relics, some cherts and argillites are leached or weathered giving light or dark outer rims, scattered rhombs suggesting siderite throughout the section occasionally concentrated in linear zones.
CLASSIFICATION: Lithic sandstone.

57-F39 - Depth 3303.2 Feet to 3303.5Feet (Pl. VII, fig. 7)

Megascopic description

SANDSTONE, Grey, medium grained, porous, slightly calcareous, glauconitic, some laminations due to concentration of glauconite, salt and pepper, siliceous cement, well sorted.

Microscopic description

TEXTURE: Medium grained sandstone, subrounded to rounded, normal packing, porosity 25 to 30%, cementation silica and calcite, well sorted, Clastic.
STRUCTURE: None observed.
MINERALOGY: Quartz 55%, Siliceous rock fragments 40% - fine grained cherts and argillites and some siliceous volcanics and quartzites, Glauconite 3%, Calcite 2%, Alkali felspars 1%, Muscovite less than 1%, Twinned plagioclase less than 1%, Rutile less than 1%.
CEMENT: Total cement 6% - silica 4% as overgrowths on quartz - calcite 2%.
SIGNIFICANCE: Grey due to presence of rock fragments.
REMARKS: Rock fragments are more angular than quartz.
CLASSIFICATION: Lithic sandstone.

57-F46 - Depth 3304.7 Feet to 3304.9 Feet (Pl. VI figs. 1, 4, 5, 6, 9)

Megascopic description

SANDSTONE, Grey with green appearance due to glauconite and brown bands which look like sideritic shale, fine grained, salt and pepper, slightly calcareous, glauconitic, siliceous cement, well sorted.

Microscopic description

TEXTURE: Fine grained sandstone, subrounded to subangular, tight packing, porosity less than 1%, cementation silica and calcite, well sorted, matrix appears to be ferruginous, Clastic.
STRUCTURE: Shaly bands parallel to bedding but discontinuous.
MINERALOGY: Quartz 50%, Siliceous rock fragments 30% mainly chert and argillites with some siliceous volcanics and quartzites, Glauconite 10%, Calcite 3%, Muscovite less than 1%, Matrix 5% (not in bands) argillaceous material which is ferruginous.
CEMENT: Total cement 6% - silica 3% as overgrowths on quartz - calcite 3%.
SIGNIFICANCE: Grey due to presence of rock fragments in bands reddish brown due to presence of iron.
REMARKS: Some rock fragments are weathered or leached as is shown by light or dark rims, quartz grains are strained, the ferruginous shaly bands are discontinuous and the lower contact with sandstone shows movement of shaly material into the underlying sandstone, which may be due to compaction.
CLASSIFICATION: Lithic sandstone.

57-F50 - Depth 3310.3 Feet to 3310.8 Feet

Megascopic description

SANDSTONE, light grey, fine grained, porous, noncalcareous, ill defined laminations due to variation in porosity, slightly glauconitic, medium to well sorted, cement probably silica, salt and pepper.

Microscopic description

TEXTURE: Fine grained sandstone, subrounded to rounded, normal packing, porosity 20% to 25%, cementation silica, well sorted, Clastic.
STRUCTURE: Shows preference of orientation of grains, long axis parallel to depositional surface.
MINERALOGY: Quartz 60%, Siliceous rock fragments 35% - composed of chert, argillite, quartzite and possibly siliceous volcanics, Alkali felspar 2%, Glauconite less than 1%, Calcite less than 1%, Twinned plagioclase less than 1%, Zircon less than 1%, Muscovite less than 1%.
CEMENT: Total cement 8% - as silica overgrowth on quartz.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments.
REMARKS: Rock fragments seem to be more angular than quartz, Quartz overgrowths control porosity as chert is concentrated in certain bands or laminae which has little cement and thus better porosity.
CLASSIFICATION: Lithic sandstone.

57-F51 - Depth 3318.6 Feet to 3319 Feet.

Megascopic description

SANDSTONE, grey with thin streaks of dark argillaceous material, fine grained, salt and pepper, glauconitic, porous, animal burrows, slightly calcareous, well sorted.

Microscopic description

TEXTURE: Fine grained sandstone, quartz grains angular to rounded, rock fragments subrounded to rounded, porosity 5%, cementation silica, well sorted, Clastic.
STRUCTURE: Argillaceous laminae roughly parallel to bedding.
MINERALOGY: Quartz 55%, Siliceous rock fragments 30% - mainly chert and argillite with minor quartzite and siliceous volcanics, Black opaques 3%, Glauconite 1%, Collophane less than 1%, Chlorite less than 1%, Twinned plagioclase less than 1%, Matrix 10% - composed of fine silt and illitic clay material.
CEMENT: Total cement 4% as silica overgrowths.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments.
CLASSIFICATION: Lithic sandstone.

57-F52 - Depth 3325.5 Feet to 3326 Feet. (Pl. VI, fig. 8.)

Megascopic description

SANDSTONE, dark grey with light grey streaks, very fine grained, salt and pepper, slightly glauconitic, noncalcareous, worm burrows, reworked poor sorting.

Microscopic description

TEXTURE: Very fine grained sandstone, subangular to subrounded, porosity less than 1%, cementation some silica overgrowth, poorly sorted, clastic.
STRUCTURE: Bands of argillaceous matrix concentrated parallel to bedding, borings shown by concentration of quartz grains in elliptical shapes.
MINERALOGY: Quartz 25%, Siliceous rock fragments 20% - mainly chert and argillite with some quartzite and siliceous volcanics, Glauconite less than 1%, Twinned plagioclase less than 1%, Chlorite less than 1%, Pyrite less than 1%, Calcite less than 1%, Matrix 50% - fine silt and illitic clay material.
CEMENT: Total cement 1% - as silica overgrowths on quartz grains.
SIGNIFICANCE OF COLOUR: Dark areas due to presence of rock fragments and matrix whereas light areas show a concentration of quartz.
REMARKS: Pyrite is concentrated in certain areas but its overall abundance is low.
CLASSIFICATION: Lithic sandstone.

57-F53 - Depth 3338.1 Feet to 3338.3 Feet (Pl. VII, fig. 12)

Megascopic description

SANDSTONE, dark grey, very fine grained, salt and pepper, slightly glauconitic, pyritic, very slightly calcareous, argillaceous and siliceous cement, slight porosity, poor sorting.

Microscopic description

TEXTURE: Very fine grained sandstone, subangular to subrounded, tight packing, porosity less than 1%, cementation silica with matrix of fine silt and argillaceous material, poor sorting, Clastic.
STRUCTURE: None observed.
MINERALOGY: Quartz 50%, Siliceous rock fragments 15% - composed of chert, argillite, quartzite, and siliceous volcanics, Pyrite 4%, Colophane 2%, Glauconite less than 1%, Zircon less than 1%, Twinned plagioclase less than 1%, Muscovite less than 1%, Calcite less than 1%, Matrix 30% - fine grained silt and illitic clay material.
CEMENT: Total cement 3% - as silica overgrowths on quartz and a trace of calcite.
SIGNIFICANCE OF COLOUR: Grey due to presence of rock fragments and matrix.
REMARKS: Some areas have concentration of Matrix, quartz overgrowths sometimes give euhedral outline, pyrite concentrated in certain areas.
CLASSIFICATION: Lithic sandstone.

57-F64 - Depth 3341.7 Feet to 3342 Feet (Pl. VII, fig. 11)

Megascopic description

SANDSTONE, dark grey to brown, very fine grained, salt and pepper, slightly glauconitic, noncalcareous, siliceous cement, well sorted, pyritic.

Microscopic description

TEXTURE: Fine grained sandstone, subangular to angular, carbonate grains same size as quartz grains, medium sorting - quartz and rock fragments, well sorted - carbonate grains, Clastic.
STRUCTURE: None observed.
MINERALOGY: Siderite 50%, Quartz 35%, Siliceous rock fragments 10% - chert and argillite, Glauconite less than 1%.
CEMENT: Total cement less than 1% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Brown due to siderite, grey due to presence of rock fragments.
REMARKS: The carbonate is detrital but may have been reworked from within the basin.
CLASSIFICATION: Lithic sandstone.

57-F66 - Depth 3349.2 Feet to 3349.6 Feet (Pl. VII, fig. 10)

Megascopic description

SANDSTONE; greyish brown with a light band 1 to 2 cm. wide, fine grained, salt and pepper, slightly glauconitic, dark band more porous but not calcareous, light band calcareous cement, tight, some siliceous cement, medium sorted.

Microscopic description

TEXTURE: Fine grained sandstone, subrounded to subangular, tight packing, porosity 5%, cementation silica and calcite, medium sorting, Clastic.
STRUCTURE: Zones of porosity have been infilled by calcite - the quartz grains in these areas are larger than the quartz grains in the noncalcareous zones.
MINERALOGY: Quartz 65%, Siliceous rock fragments 25% - mainly chert and argillite with some quartzite and siliceous volcanics, Calcite 8% - in calcareous zone, Pyrite 2%, Twinned plagioclase less than 1%, Glauconite less than 1%, Collophane less than 1%, Matrix 5% - fine silt and illitic clay material.
CEMENT: Total cement 13% - Calcite 8%, Silica 5% as overgrowths on quartz.
SIGNIFICANCE OF COLOUR: DArk due to matrix and rock fragments.
REMARKS: Matrix is confined to certain areas, some quartz crystals are euhedral due to overgrowths.
CLASSIFICATION: Lithic sandstone.

Imperial Joffre 2-21V
Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M

57-S7 - Depth 4728.5 Feet to 4729 Feet. (Pl. VII, fig. 3)

Megascopic description

SANDSTONE, grey, coarse grained, cross-bedded, salt and pepper, calcareous, shows authigenic growth of calcite crystalls which surround other grains, well sorted.

Microscopic description

TEXTURE: Coarse grained sandstone, subrounded to rounded, loose packing, no porosity, cementation calcite, well sorted, Clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 40% - mainly chert and argillite, some quartzite grains, Quartz 10%, Twinned plagioclase 1%, Calcite 45%.
CEMENT: Total cement 45% - as authigenic calcite.
SIGNIFICANCE OF COLOUR: Dark due to presence of rock fragments.
REMARKS: This section was poorly prepared and is pulled apart.
CLASSIFICATION: Lithic sandstone.

57-S8 - Depth 4730.1 Feet to 4730.4 Feet

Megascopic description

SANDSTONE, grey, medium grained, salt and pepper, non-calcareous, medium sorting, oil stained, slight porosity.

Microscopic description

TEXTURE: Coarse grained sandstone, subangular to subrounded, can not determine packing, porosity or cementation as slide is very poor, sorting medium, clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments, Quartz, Calcite.
CEMENT: Not determined.
SIGNIFICANCE OF COLOUR: Dark because of the presence of rock fragments.
REMARKS: Very poor thin section.
CLASSIFICATION: Lithic sandstone.

57-S9 - Depth 4731.5 Feet to 4731.8 Feet

Megascopic description

CONGLOMERATE, Grey- chert pebbles black, fine pebble grain size, salt and pepper, calcareous, no porosity, poor sorting.

Microscopic description

TEXTURE: Fine pebble grained conglomerate, large chert pebbles rounded, finer fraction subangular to subrounded, tight packing, cementation silica and calcite.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 50% - chert and argillite, Quartz 30%, Calcite 15%, Callophane 1%.
CEMENT: Total cement 17% - Calcite 15%, Silica 2% as quartz overgrowths.
SIGNIFICANCE OF COLOUR: Dark due to presence of rock fragments.
REMARKS: Very poor slide.
CLASSIFICATION: Lithic pebble conglomerate.

57-S10 - Depth 4738.1 Feet to 4738.3 Feet

Megascopic description

SANDSTONE, Grey with brown patches due to concentration of siderite, medium grained, salt and pepper, medium sorting, some disseminated pyrite, sideritic concentration in bands, non-calcareous, burrows,

Microscopic description

TEXTURE: Medium grained sandstone, rock fragments subrounded to rounded, quartz grains subrounded to subangular, tight packing, cementation silica, some quartz overgrowth, medium to poor sorting, Clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 60% - mainly chert and argillite, Quartz 25%, Siderite 10%, Collophane less than 1%, Pyrite less than 1%.
CEMENT: Total cement 2% as silica overgrowths on quartz.
SIGNIFICANCE OF COLOUR: Dark due to presence of rock fragments and brown due to siderite content.
REMARKS: Very poor thin section.
CLASSIFICATION: Lithic sandstone.

57-S11 - Depth 4750.5 Feet to 4750.8 Feet

Megascopic description

SANDSTONE, dark grey, very coarse grains, salt and pepper, calcareous, poorly sorted, some chert or argillite grains pyritized, slight porosity.

Microscopic description

TEXTURE: Very coarse grained sandstone, subrounded to rounded, normal packing, porosity less than 1%, comentation silica and calcite, poorly sorted, Clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 55% - mainly chert and argillite with some quartzite and siliceous volcanics, Quartz 15%, Calcite 25%, Pyrite 3%, Twinned plagioclase less than 1%.
CEMENT: Total amount 26% - Calcite 25%, Silica 1% as overgrowths.
SIGNIFICANCE OF COLOUR: Dark due to presence of rock fragments.
REMARKS: Organic remains are present in some chert fragments, authigenic overgrowths on quartz give euhedral crystals, pyrite in replacing some chert and argillite fragments, some cherts and argillites have fracture fillings of quartz.
CLASSIFICATION: Lithic sandstone.

57-S15 - Depth 4759.8 Feet to 4759.9 Feet

Megascopic description

SANDSTONE, dark grey, coarse grained, salt and pepper, glauconitic, calcareous, poor sorting, some pyrite, some areas appear to be medium grained to fine grained, more glauconite in coarse grained areas.

Microscopic description

TEXTURE: Fine grained sandstone, subangular to subrounded, no porosity, tignt packing, cementation silica and calcite, poor sorting, Clastic.
STRUCTURE: None observed.
MINERALOGY: Siliceous rock fragments 50% - mainly chert and argillite, Quartz 45%, Calcite 4%.
CEMENT: Total cement 8% - Silica 4% as overgrowths, Calcite 4%.
SIGNIFICANCE OF COLOUR: Dark due to presence of rock fragments.
REMARKS: Very poor thin section.
CLASSIFICATION: Litnic sandstone.

57-S16 - Depth 4760.6 Feet to 4761 Feet

Megascopic description

SANDSTONE, grey with brown bands of siderite $\frac{1}{4}$ inch to 2 inches thick, some bands coarse sandstone others fine sandstone and medium grained sandstone, medium sorting, glauconitic, salt and pepper, calcareous.

Microscopic description

TEXTURE, Medium grained sandstone, subangular to rounded, no porosity, cementation silica and some calcite, poor sorting, Clastic.
STRUCTURE: Siderite bands parallel to bedding.
MINERALOGY:: Siderite 45%, Siliceous rock fragments 30% - mainly chert and argillite, Quartz 20%, Glauconite (not in section but you can see the voids it occupied). Calcite, not in section now.
CEMENT: Total cement 25 - silica overgrowths.
SIGNIFICANCE OF COLOUR: Dark due to rock fragments, brown due to siderite.
REMARKS: Very poor thin section.
CLASSIFICATION: Lithic sandstone.

57-S17 - Depth 4762.6 Feet to 4762.9 Feet

Megascopic description

SANDSTONE, greyist brown, fine grained, salt and pepper, glauconitic, elastic siderite 60% to 70%, silt size, no porosity, bimodal and well sorted, small pieces of carbonaceous material throughout.

Microscopic description

TEXTURE: Fine sandstone grain size, subangular to subrounded, no porosity, cementation none, well sorted (binodal siderite medium

silt, rest fine grained sandstone), Clastic.
STRUCTURE: None observed.
MINERALOGY: Siderite 60%, Quartz 20%, Siliceous rock fragments 15% - mainly chert and argillite with some quartzite, Glauconite approximately 4% (not seen in thin section), Twinned plagioclase less than 1%, Calcite less than 1%.
CEMENT: None.
SIGNIFICANCE OF COLOR: Dark due to presence of siderite.
REMARKS: Glauconite is the same size as the quartz grains but is absent in the thin section due to poor preparation.
CLASSIFICATION: Siderite lithic sandstone.

APPENDIX C

LOCATION OF HEAVY MINERAL SAMPLES

Imperial Norbuck 2-6
Lsd. 2, Sec. 6, Twp. 47, Rge. 4 W5M
Viking Top 5579 Feet

Sample Number	Depth
Norbuck 1	5608 Feet to 5613 Feet

Imperial Joffre 2-21V
Lsd. 2, Sec. 21, Twp. 38, Rge. 25 W4M
Viking Top 4728 Feet

Sample Number	Depth
Joffre 1	4756.3 Feet to 4757 Feet
Joffre 2	4761.3 Feet to 4763.4 Feet

Superior Joseph Lake 11
Lsd. 12, Sec. 13, Twp. 50, Rge. 22 W4M
Viking Top 3220 Feet

Sample Number	Depth
Joe Lake 1	3260 Feet to 3268 Feet
	3274 Feet to 3284.5 Feet

Imperial Armena 6-11V
Lsd. 6, Sec. 11, Twp. 48, Rge. 21 W4M
Viking Top 3272 Feet

Sample Number	Depth
Armena 1	3300.5 Feet to 3305.4 Feet
Armena 2	3338.3 Feet to 3340.5 Feet

APPENDIX D

LOCATION OF MICROFOSSIL SAMPLES

Imperial Norbuck 2-6
Lsd. 2, Sec. 6, Twp. 47, Rge. 4W5M
Viking Top 5579 Feet.

Sample Number	Depth
566	5566 Feet to 5568.5 Feet
568	5568.5 " " 5571 "
571	5571 " " 5573.5 "
573	5573.5 " " 5576 "
576	5576 " " 5578.5 "
578	5578.5 " " 5581 "
581	5581 " " 5583.5 "
584	5584.5 " " 5586 "
587	5587.5 " " 5590 "
592	5592.5 " " 5593 "
598	5598 " " 5599 "
640	5640 " " 5641 "
654	5654 " " 5654.5 "
669	5669 " " 5669.5 "
679	5679 " " 5679.5 "
685	5685 " " 5685.5 "
689	5689 " " 5689.5 "
695	5695 " " 5696 "
696	5696.5 " " 5697.5 "

Imperial Joffre 2-21V
Lsd. 2, Sec. 21, Twp. 38, Rge. 25W4M
Viking Top 4728 Feet.

Sample Number	Depth
2-20	4720 Feet to 4723 Feet
2-23	4723 " " 4726 "
2-26	4726 " " 4728 "
2-30	4730 Feet
2-35	4735 "
2-54	4754 "
2-75	4775 "
2-76	4776 "
2-81	4781 Feet to 4786 Feet
2-86	4786 " " 4788 "

Superior Joseph Lake 11
Lsd. 12, Sec. 13, Twp. 50 Rge. 22W4M
Viking Top 3220 Feet.

Sample Number	Depth
11-29	3229 Feet to 3234 Feet
11-34	3234 Feet to 3239 Feet
11-39	3239 Feet to 3244 Feet
11-44	3244 Feet to 3249 Feet
11-49	3249 Feet to 3254 Feet
11-54	3254 Feet to 3259 Feet

Imperial Armena 6-11V
Lsd. 6, Sec. 11, Twp. 48, Rge. 21W4M
Viking Top 3272 Feet.

Sample Number	Depth
6-84	3284 Feet to 3284.4 Feet
6-88	3288 Feet to 3288.4 Feet
6-33	3333 Feet to 3333.4 Feet

EXPLANATION OF PLATE I

Photographs of Core

Figure 1: Conglomerate, poorly sorted; x1; Imperial Joffre 2-21V, depth 4731.5 feet, 3.5 feet below the top of the Viking formation; thin section description page XXVI.

Figure 2: Conglomerate; poorly sorted, incipient imbricate structure; X1; Imperial Norbuck 2-6, depth 5600 feet, 21 feet below the top of the Viking formation; thin section description page XIV.

Figure 3: Typical rapidly varying lithology; lower bed somewhat graded; X1; Imperial Joffre 2-21V, depth 4750.8 feet, 23 feet below the top of the Viking formation.

Figure 4: Coarse sandstone overlying, shale with sandstone lenses; X1; Imperial Armena 6-11V, depth 3295.5 feet, 23.5 feet below the top of the Viking formation; thin section description, page XIX.

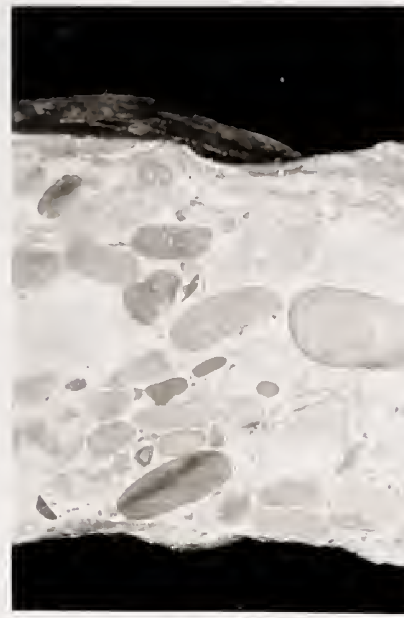
Figure 1.

Figure 2.

Figure 3.

Figure 4.

PLATE I.



EXPLANATION OF PLATE II

Photographs of Core

Figure 1: Conglomerate, porous, main pay horizon; X1; Imperial Joffre 2-21V, depth 4756.3 feet, 28 feet below the top of the Viking formation.

Figure 2: Sandstone, shows alternating laminae, more porous along dark zones where there is not as much quartz overgrowth; X1; Imperial Armena 6-11V, depth 3310.3 feet, 38 feet below the top of the Viking formation; thin section description page XXII.

Figure 3: Sandstone, cross-bedded, authigenic calcite cement; X1; Imperial Joffre 2-21V, depth 4728 feet, this is taken as the top of the Viking formation; thin section description page XXV.

Figure 4: Siltstone, fine alternating light and dark laminae, cross-bedded at the base; X1; Imperial Norbuck 2-6, depth 5589 feet, 10 feet below the top of the Viking formation.

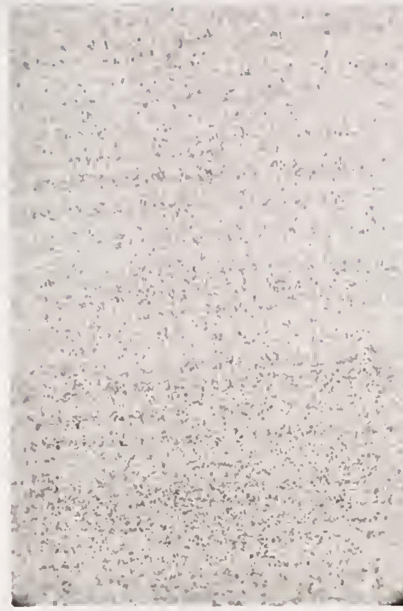
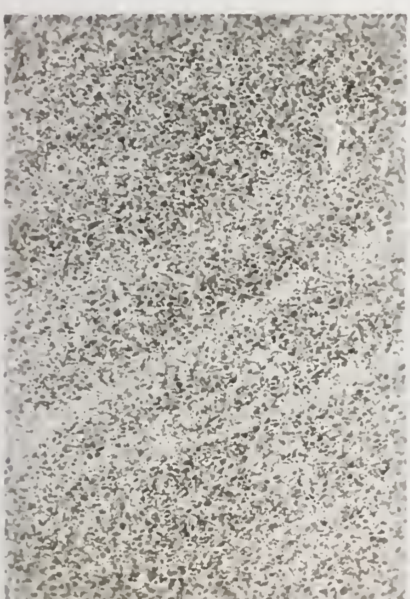
Figure 1.

Figure 2.

Figure 3.

Figure 4.

PLATE II.


EXPLANATION OF PLATE III

Photographs of Core

Figure 1: Siltstone and shale interbedded, siltstone at top is cross-bedded, siltstone and shale mixture show reworking, cut and fill, and animal burrows; X1; Imperial Armena 6-11V, depth 3281.3 feet, 9.3 feet below the top of the Viking formation; thin section description of cross-bedded siltstone page XVIII.

Figure 2: Siltstone and shale interbedded, shows reworking cut and fill, and animal burrows; X1; Imperial Armena 6-11V, depth 3281.6 feet, 5.6 feet below the top of the Viking formation.

Figure 3: Siltstone, cross-bedded, overlies and is overlain by rework siltstone and shale, animal burrows present; X1; Imperial Armena 6-11V, depth 3286 feet, 14 feet below the top of the Viking formation.

Figure 4: Sandstone, cross-bedded; X1; Imperial Norbuck 2-6, depth 5584 feet, 5 feet below the top of the Viking formation; thin section description page XII.

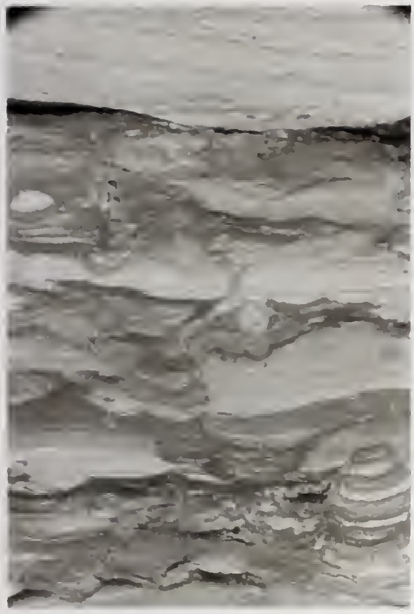
Figure 1.

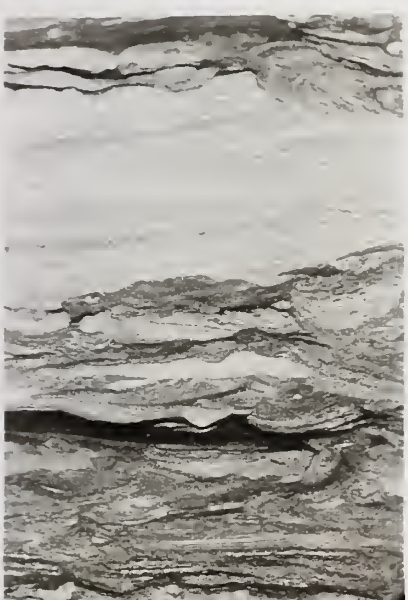
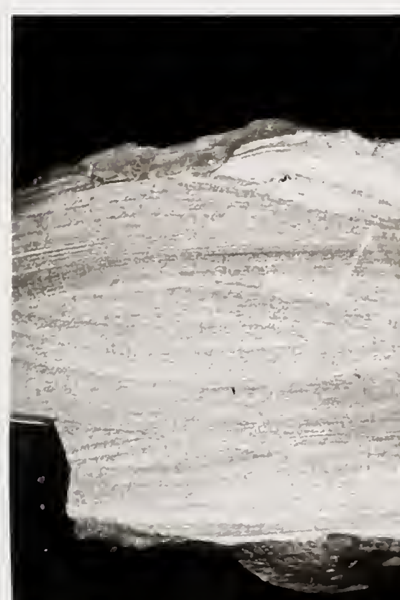
Figure 2.

Figure 3.

Figure 4.

PLATE III.



EXPLANATION OF PLATE IV

Photographs of Core

Figure 1: Sandstone and shale intermixed; X1; Imperial Armena 6-11V, depth 3325.5 feet, 53.5 feet below the top of the Viking; thin section description page XXIII.

Figure 2: Sandstone and shale showing contorted bedding; X1; Imperial Norbuck 2-6, depth 5610 feet, 31 feet below the top of the Viking formation.

Figure 3: Sandstone and shale interbedded, animal burrows; X1; Imperial Norbuck 2-6, depth 5604 feet, 23.1 feet below the top of the Viking formation; thin section description page XIV.

Figure 4: Sandstone and shale interbedded, animal burrows; X1; Imperial Joffre 2-21V, depth 4743 feet, 15 feet below the top of the Viking formation.

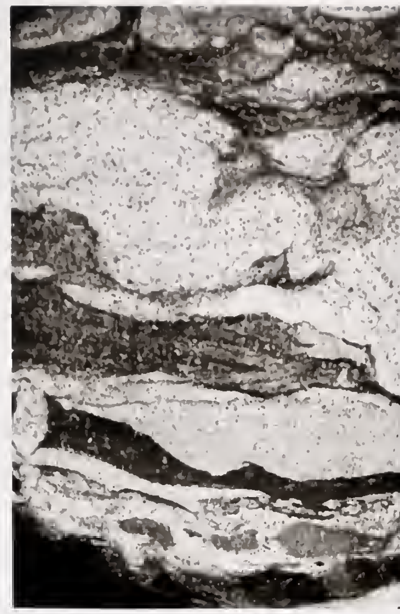
Figure 1.

Figure 2.

Figure 3.

Figure 4.

PLATE IV.



EXPLANATION OF PLATE V

Photographs of Core

Figure 1: Sandstone, with siderite stringers and small pieces of wood, animal burrows through siderite; X1; Imperial Armena 6-11V, depth 3303.9 feet, 31.9 feet below the top of the Viking formation.

Figure 2: Sandstone and shale intermixed, reworked; X1; Imperial Joffre 2-21V, depth 4766.7 feet, 38.7 feet below the top of the Viking formation.

Figure 3: Sandstone and shale intermixed, reworked; X1; Imperial Norbuck 2-6, depth 5625 feet, 46 feet below the top of the Viking formation.

Figure 4: Sandstone and shale intermixed, reworked, animal burrows near base; X1; Imperial Armena 6-11V, depth 3318.6 feet, 46.6 feet below the top of the Viking formation; thin section description page XXXIII.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

PLATE V.




EXPLANATION OF PLATE VI

Photomicrographs of Thin Sections

Figure 1: Specimen 57-F46; Siderite-dark, glauconite-grey, quartz and rock fragments-white; X25; Imperial Armena 6-11V, depth 3304.7 feet, 32.7 feet below the top of the Viking formation; described on page XXI.

Figure 2: Specimen 57-F26; Carbonate-small rhombs, glauconite-even dark grey, quartz-white, rock fragments-speckled grey, calcite-angular high relief; X25; Imperial Armena 6-11V, depth 3300.6 feet, 28.6 feet below the top of the Viking formation; description on page XX.

Figure 3: Specimen 57-F18; Medium grained siltstone with an argillaceous matrix; X16; Imperial Armena 6-11V, depth 3281.3 feet, 9.3 feet below the top of the Viking formation; described on page XVIII.

Figure 4: Specimen 57-F46; See Figure 1; X25.

Figure 5: Specimen 57-F46; See Figure 1; X25; angular fragments that are clear and have high relief are calcite.

Figure 6: Specimen 57-F46; See Figure 1; X50; large grain in the center of the field is glauconite.

Figure 7: Specimen 57-F78; Very fine grained sandstone; concentration of dark minerals vaguely shows inclined cross-bedding planes; X25; Imperial Norbuck 2-6, depth 5584 feet, 5 feet below the top of the Viking formation; described on page XII.

Figure 8: Specimen 57-F52; Very fine grained sandstone, poorly sorted with argillaceous matrix; X25; Imperial Armena 6-11V, depth 3325.5 feet, 53.5 feet below the top of the Viking formation; described on page XXIII.

Figure 9: Specimen 57-F46; See Figure 1; X50.

Figure 10: Specimen 57-F107; Very fine silt size sideritic ironstone; elliptical and circular shaped animal borings with higher concentration of quartz; X25; Imperial Norbuck 2-6, depth 5633 feet, 54 feet below the top of the Viking formation; description on page XVI.

Figure 11: Specimen 57-F89; Fine grained sandstone showing poor sorting and concentration of argillaceous matrix; X25; Imperial Norbuck 2-6, depth 5608 feet, 29 feet below the top of the Viking formation; described on page XV.

Figure 12: Specimen 57-F88; Very fine grained sandstone with pyritic argillaceous laminae, poorly sorted; X25; Imperial Norbuck 2-6, depth 5604 feet, 25 feet below the top of the Viking formation; described on page XIV.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

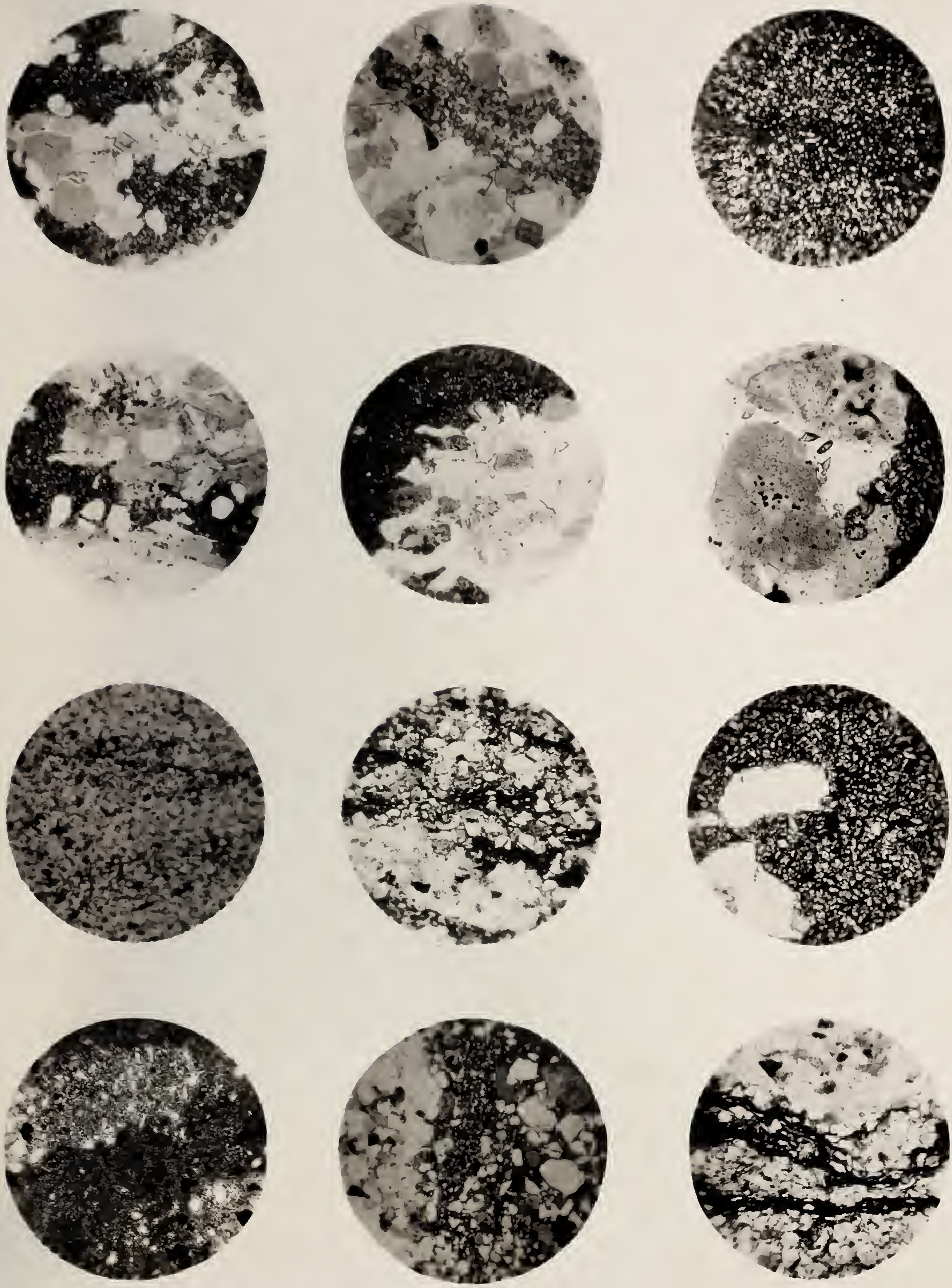
Figure 9.

Figure 10.

Figure 11.

Figure 12.

PLATE VI.



EXPLANATION OF PLATE VII

Photomicrographs of Thin Sections

Figure 1: Specimen 57-F87; Conglomerate; portions of two pebbles with interstitial sand matrix are shown; dark fragments are chert, and other siliceous rocks, white fragments are quartz; X25; Imperial Norbuck 2-6, depth 5600 feet, 21 feet below the top of the Viking formation; described on page XIV.

Figure 2: Specimen 57-F83; Conglomerate; grey and black fragments are chert and altered siliceous rock, white fragments are quartz; large pebble occupying top half of figure has a fracture infilled with quartz; X25; Imperial Norbuck 2-6, depth 5598 feet, 19 feet below the top of the Viking formation; described on page XIII.

Figure 3: Specimen 57-87; Coarse grained sandstone; mottled black and grey fragments are chert and argillite, white fragments are quartz, all fragments are surrounded by a Calcite cement; X25; Imperial Joffre 2-21V, depth 4728.5 feet, 0.5 feet below the top of the Viking formation; described on page XXV.

Figure 4: Specimen 57-F24; Medium grained sandstone; grey fragments over chert and argillite, white fragments are quartz, angular grains with high relief are calcite; X25; Imperial Armena 6-11V, depth 3299 feet, 27 feet below the top of the Viking formation; described on page XX.

Figure 5: Specimen 57-F23; Coarse grained sandstone, dark fragments are chert and argillite, white fragments are quartz, dark grey material surrounding grains is siliceous and argillaceous matrix; 16X; Imperial Armena 6-11V, depth 3295.5 feet, 23.5 feet below the top of the Viking formation described on page XIX.

Figure 6: Specimen 57-F22; Medium grained sandstone; grey and mottled fragments are chert and other siliceous rocks, white fragments are quartz, long black prismatic fragment is collophane; 25X; Imperial Armena 6-11V, depth 3293.4 feet, 21.4 feet below the top of the Viking formation; described on page XIX.

Figure 7: Specimen 57-F39; Medium grained sandstone; light grey fragments are chert, mottled medium grey fragments are other siliceous rocks, two rounded dark grey grains are glauconite, black angular grain is chert, white fragments are quartz, medium grey prismatic fragment near center of field is collophane, angular grains with high relief are calcite; 25X; Imperial Armena 6-11V, depth 3303.2 feet, 31.2 feet below the top of the Viking formation; described on page XXI.

Figure 8: Specimen 57-F26; Medium grained sandstone, light grey fragments are chert, white fragments are quartz, rounded medium grey fragment at lower left is glauconite, grey tabular fragment near top is collophane, black fragments are argillaceous rocks, angular grains with high relief are calcite; 25X; Imperial Armena 6-11V, depth 3300.6 feet, 28.6 feet below the top of the Viking formation; described on page XX.

Figure 9: Specimen 57-F24; Coarse grained sandstone, bimodal, dark speckled fragments are chert and argillite, white and even grey fragments are quartz; crossed nicols; X25; Imperial Armena 6-11V, depth 3298.9 feet, 26.9 feet below the top of the Viking formation; described on page XX.

Figure 10: Specimen 57-F66; Fine to medium grained sandstone, grey to black fragments are chert and siliceous rocks, white fragments are quartz showing overgrowths, angular grains with high relief are calcite; 25X; Imperial Armena 6-11V, depth 3349.2 feet, 77.2 feet below the top of the Viking formation; described on page XXV.

Figure 11: Specimen 57-F64; Very fine grained sandstone, grey grains with high relief are siderite, white fragments are quartz, dark fragments are chert and argillite; 25X; Imperial Armena 6-11V, depth 3341.7 feet, 69.7 feet below the top of the Viking formation; described on page XXIV.

Figure 12: Specimen 57-F53; Fine grained sandstone, grey to black fragments are chert and other siliceous rocks, white fragments are quartz, one quartz grain in the upper left quadrant shows an overgrowth, dark material surrounding grains is an argillaceous matrix; 25X; Imperial Armena 6-11V, depth 3338.1 feet, 66.1 feet below the top of the Viking formation; described on page XXIV.

Figure 1.

Figure 2.

Figure 3.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

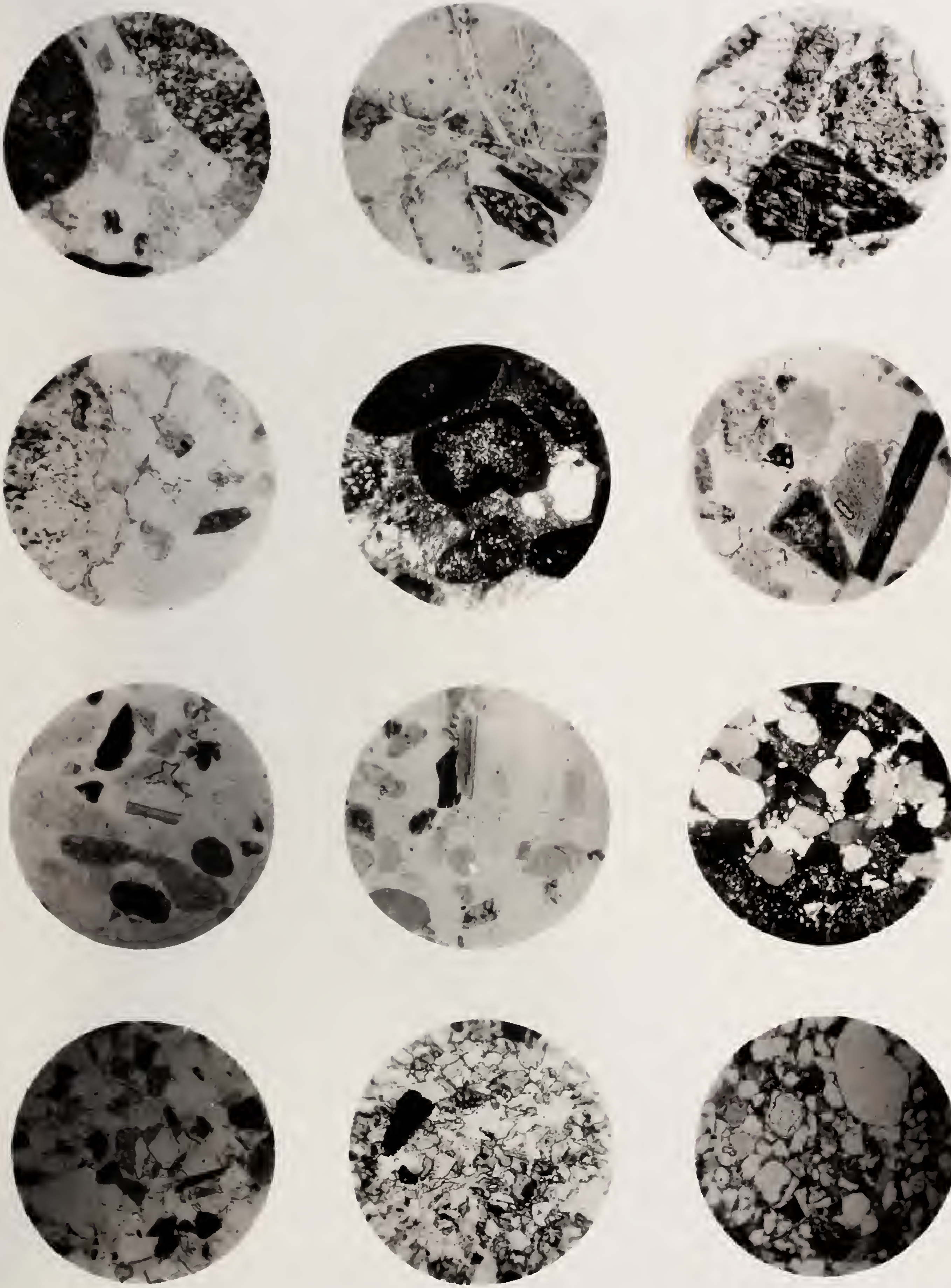
Figure 9.

Figure 10.

Figure 11.

Figure 12.

PLATE VII



EXPLANATION OF PLATE VIII

Photomicrographs of Heavy Minerals

Figure 1: Apatite, note inclusion parallel to the c-axis; X100; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 2: Apatite, note inclusions parallel to the c-axis; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 3: Brookite; X180; Imperial Armena 6-11V, sample Armena #1.

Figure 4: Collophane; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 5: Garnet, pink; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 6: Hornblende, green; X180; Imperial Joffre 2-21V, sample Joffre #2.

Figure 7: Monazite, brown; X180; Imperial Norbuck 2-6, sample Norbuck #1.

Figure 8: Siderite; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 9: Sphene euhedral crystal with well developed faces; X180; Superior Joseph Lake 11, sample Joe Lake #1.

PLATE 8

EXPLANATION OF PLATE IX

Photomicrographs of Heavy Minerals

Figure 1: Zircon, subhedral with inclusions; X130; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 2: Zircon, subhedral with inclusions; X180; Imperial Norbuck 2-6, sample Norbuck #1.

Figure 3: Zircon, rounded with inclusions; X180; Imperial Norbuck 2-6, sample Norbuck #1.

Figure 4: Zircon, rounded purple hyacinth with inclusions and pitted surface; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 5: Zircon, rounded with pitted surface; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 6: Zircon, rounded; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 7: Tourmaline, dark green pleochroic to pink, rounded, inclusions present; X180; Imperial Norbuck 2-6, sample Norbuck #1.

Figure 8: Tourmaline, dark green pleochroic to pink, subhedral; X130; Imperial Armena 6-11V, sample Armena #2.

Figure 9: Tourmaline, dark green pleochroic to pinkish brown, angular; X180; Imperial Norbuck 2-6, sample Norbuck #1.

Figure 10: Tourmaline, dark green pleochroic to pinkish brown,rounded; X180; Superior Joseph Lake 11, sample Joe Lake #1.

Figure 11: Tourmaline, dark green pleochroic to light brown, rounded; X180; Imperial Armena 6-11V, sample Armena #2.

Figure 12: Tourmaline, dark green pleochroic to greenish brown, rounded authigenic overgrowth, at top; X180; Superior Joseph Lake 11, sample Joe Lake #1.

PLATE 9